COMMUNITY DYNAMICS AND DIVERSITY OF GROUND DWELLING ARTHROPODS ASSEMBLAGES IN A MAIZE BASED AGROFORESTRY SYSTEM IN MTWAPA, COASTAL KENYA

BY

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DECLARATION BY CANDIDATE

This is my original work and has not been presented for a degree in any other University or any other award.

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DECLARATION BY SUPERVISOR

I confirm that the work reported in this thesis was carried out by the candidate under my supervision.

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DEDICATION

This thesis is dedicated to my husband, Simon and my children Samuel and Susan with all my love.

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ABSTRACT

The effect of diversification and intensification in agroecosystems to arthropod diversity is not well understood, mainly because conservationists have greatly ignored agroecosystems, while most of the research work has been for a long time, directed towards the so called undisturbed systems like the natural forests. This study was intended to contribute towards evaluating relationships in agroecosystems and to assess the impacts of various cropping systems on the diversity and dynamics of soil dwelling arthropods.

During the first phase of this study, Pitfall trapping was conducted every two weeks in all the plots from June 1999 to February 2000 and the arthropods collected classified to family level. Treatments consisted of different crop combinations and practices involving alley cropping and intercropping of maize, cowpea, Leucaena, and Gliricidia (mlgc), mulching (mu) and use of pesticides (p). An additional unmanaged field (um) was sampled for comparison with the managed agroecosystems. This gave a total of eleven treatments in 1999-2000 cropping seasons (June 1999-February 2000). During the 2000-2001 (June 2000-February 2001) cropping seasons two additional sole cowpea treatments, one of which was treated with pesticides, (c and c+p) were sampled. Pitfalls were serviced weekly instead of fortnightly as in the previous seasons and arthropods identified further to Genus and species level where possible. Thereafter, Shannon Weiner (H') and Simpson-Yule (D) diversity indices, evenness (J) and species richness (S), were calculated for all the plots. The data obtained was then subjected to analysis of variance to test for treatment differences.

A total of 8,184 arthropods belonging to 20 families were collected during the long and short rains of 1999-2000. The family Formicidae was the most abundant accounting for 84.34% of the total samples. The unmanaged system (um) and the maize intercropped with leucaena, gliricidia and cowpea (mlgc) had the highest Species richness (S=8.25, for both treatments). There was a significant difference (P<0.05) only in evenness with (um) being significantly different from all the others, and the maize monocrop (m) being significantly different from maize+cowpea (mc). During the long and short rains of 2000-2001 a total number of 146 958 arthropods were collected belonging to the five major orders in the samples, namely Hymenoptera, Coleoptera, Orthoptera, Blattoidea and Aranae. Of the five orders, the order Hymenoptera was the most abundant (78.44%). A total number of 70 different species representing 26 families were identified. Species richness (S) was not significantly different (P>0.05) between treatments. However species diversity (D and H') and evenness (J) was significantly different (P<0.05) between treatments, with the unmanaged system recording significantly greater diversity than all the other treatments. Orthogonal contrasts however indicated that this difference was not significant between the unmanaged plots and some plots with agroforestry tree species, while it was significant in the other treatments. There was low species diversity in treatments in which pesticides were applied as well as those without mulch as compared to the mulched.

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CHAPTER ONE

1.0 GENERAL INTRODUCTIN AND LITERATURE REVIEW

1.1 Introduction

1.1.1 Agricultural practices in tropical Africa

In the last twenty years or so, there has been increasing concern about environmental impacts of agriculture in Sub-Sahara Africa and its implication for the ecological future of the continent, calling for adoption of new agricultural technology. Some of the most important environmental impacts of agriculture in the tropics include deforestation due to the lack of systematic and permanent forest protection, and savannization of forestland owing to excessively high population densities. Destruction of savannas and deterioration of forests and grasslands by intensified livestock farming has led to soil erosion and desertification, while soil degradation in medium to high mountain areas after deforestation and severe erosion, in turn, leads to the loss of natural soil fertility (Egger, 1989). These degradation processes are apparent in agricultural soils of many tropical regions and are often associated with marked changes in the activity and diversity of soil biota (Lal, 1988).

An intensification pattern, founded on a relatively inexpensive level of input and a high efficiency in the use of internal resources, is therefore urgently necessary if an economically and ecologically sustainable agriculture has to be developed. The Tropical Soil Biology and Fertility (TSBF) programme has been directed in response to this acute need (CABI, 1993).

1.1.2 Multiple cropping systems in Tropical Africa

Multiple cropping can be described as a range of practices where total production for a unit area of land in a farming year is achieved through growing of simultaneously sole crops in sequence (Andrews and Kassam, 1976). Apart from increase in land use efficiency (Francis *et. al.,* 1968), polycultures ensure food available through the season in which short-term crops like pulses are harvested and used while waiting for the longer-term cereals and root crops.

Multiple cropping systems are a part of traditional farming in Africa (Okigbo and Greenland, 1976). In East Africa, indigenous peasant farmers responsible for about 90% of food production have always practiced multiple cropping (Abasa, 1983). Throughout the tropics, such farmers have long used crop diversity to minimize the risk of crop failure, improve nutrition and produce high yields of particular crops (Litsinger and Moody, 1976). African agriculture is typified by farmers who cultivate holdings from less than one hectare to a few hectares in agroforestry systems composed of annual crops associated with trees (Bishaw *et. al.,* 1994; Zethner, 1995). Crops are often cultivated in mixtures of annual and perennial species under scattered trees (e.g., parklands of semi arid areas) or annual species intercropped or alley cropped with woody species (e.g., humid areas). These traditional agroforestry systems ensure food security of annual and perennial species, optimal use of soil and space, maintenance of soil fertility, reduced insect pest attack while maintaining lower pest - control costs (Matteson *et. al.,* 1984; Dent, 1991; Zethner, 1995). For the majority of these peasant farmers, monocultures would be both disastrous and unaffordable because of the expensive agrochemicals that go with the system (Abasa, 1983). One multiple cropping system that is gaining popularity is agroforestry.

1.1.3 Agroforestry as a multiple cropping system

Cultivating trees and agricultural crops in intimate combination with one another is an ancient practice (Nair, 1993). Thus, agroforestry is a new name for a set of old practices. The origin of agroforestry as a modern scientific study was the publication in 1977 of a review of research needs, 'Trees, Food and People' (Bene *et. al.,* 1977). Since then, agroforestry has been used to refer to land use systems and technology where woody perennials (trees, shrubs, bamboo, etc.) are deliberately used on the same land-management units as agricultural crops and/or animals, in some form of spatial arrangement or temporal sequence (Lundgren and Raintree, 1982).

From its beginnings, agroforestry has contained a strong element of soil management (Young, 1997). This is found in both indigenous and modern agroforestry systems. The earliest form of agroforestry, shifting cultivation, was primarily related to the use of natural fallow to restore fertility lost during crop cultivation. Many other indigenous agroforestry systems achieved maintenance of soil fertility. For example, rotations of cereals with *Acacia senagal* gum (arabic) in the Sahel zone of Africa, or the multistrata forest cropping of Sumatra, Indonesia (Young, 1997).

In the last 15-20 years, the leguminous tree species *Leucaena leucocephala* (Lam.) de Wit. has been used as a multipurpose tree for agroforestry development in the tropics, owing to its fast growth rate and the ease with which it can be established and managed (ICRAF, 1993). Similarly, previous experiments in the southern Africa region confirmed excellent performance of *Gliricidia sepium* (Jacq.) Walp, another important agroforestry tree, in growth rate, cropping ability, biomass production and nitrogen content in the foliage biomass (ICRAF, 1993). More over, agroforestry may even reverse the impacts of some traditional farming practices in tropical Africa like slash and burn agriculture which is indiscriminately destructive to both flora and fauna (Ogol, 1996). Agroforestry with carefully selected tree species, may ameliorate the effects of habitat loss on invertebrate faunas.

In traditional agroecosystems and forestry management, increasing plant diversity has been suggested as a means to increase insect diversity and thus lower insect herbivore damage because of decreased host plant apparency, increased interspecific competition among pest and non-pest species, and improved natural enemy communities (Stamps and Linit, 1998). Compared to polyculture of either annual crops or trees, agroforestry offers an opportunity to contribute substantially to ecosystem diversity, long-term sustainability and profitability (Stamps and Linit, 1998).

Alley cropping, the production of agronomic crops between rows of trees or shrubs, has in the recent past been the most common type of agrisilviculture. It is an agroforestry system designed to overcome the management problem of the upland low-activity clay soils, and to incorporate in them a fallow component using woody species. Also called hedgerow intercropping, hedges are planted on more or less parallel rows and crops are grown in the alleys between them (Ong 1995). The rows are usually 4-10m apart. The hedges are regularly pruned. Prunings may either be removed as fodder and fuel wood, or retained on the soil. The trees function much as they do in bush fallow. That is, they provide nitrogen from atmospheric fixation, recycle nutrients from the depth, suppress weeds and increase the soil organic matter content (Ong, 1995).

Earlier syntheses of ICRAF's alley cropping experiences indicate that the current strategy of using fast growing species may be counter productive. They may be too aggressively competitive with alley crops. It would be more worthwhile therefore to select trees with non-aggressive rooting habits from climax vegetation especially if these are also adapted to very low nutrient soils. Promising tree species are *Grevillea robusta* (Proteaceae) and *Markhamia lutea* (Benth.) (Bignoiaceae), which farmers in the East African highlands plant on boundaries (Ong 1995).

As with biological investigations, more economic studies have been made on alley cropping than on any other agroforestry technology (Nair, 1990). Management of Leucaena trees at IITA in alley cropping increased the labor by about 50% over non-alley cropped plots. However, this increased labor cost was offset by both a yield increase in maize of up to 60% as well as decreased need for fertilizer (Ngambeki, 1984).

1.2 Literature Review

1.2.1 Soil fauna in agroecosystems

Soil is the habitat of plant roots and of a diverse array of organisms such as bacteria, fungi, protozoa, and invertebrate animals which all contribute to the maintenance and productivity of agroecosystems (Giller *et. al.,* 1997). Although not apparent to the naked eye, it is the most diverse habitats on earth and contains one of the most diverse assemblages of living organisms (Giller *et. al.,* 1997). A single gram of soil has been estimated to contain several thousand of species of bacteria. Among the soil fauna, some 100,000 species of protozoa, 500,000 species of nematodes (Hawksworth and Mound, 1985) are estimated to exist. Among the soil dwelling arthropods, several species of Coleoptera including over 40,000 species of Carabid beetles (Erwin *et. al.,* 1979) and some 27,000 species of Staphylinidae have been described. Other soil macrofauna already described include some 2,000 Isoptera species, 3,000 Chilopoda, 7,000 Diplopoda and an estimate of about 10,000-20,000 Collembola species (WCMC. 1992).

Soil fauna is conventionally divided into three size classes: microfauna, which include Protozoa and Nematoda; mesofauna such as Collembola, Enchytraeids and Acari and macrofauna represented by the ants, mites, beetles, spiders, termites and earthworms. These organisms play crucial and diverse functions in ecological processes in the soil. For instance, some earthworm species facilitate the residual decomposition and mineralization through a progressive fragmentation of litter, whereas other species incorporate organic matter deeper into the soil profile and promote aeration and water infiltration through the formation of deep burrows (Lee, 1985). Many earthworm species also contribute to nutrient cycling through the production of nutrient-rich casts (Beare *et. al.,* 1997).

1.2.2 Ecological functioning and importance of soil arthropods

Arthropod species in agroecosystems play an important and often critical ecological role as herbivore converters, links in the food webs of local ecosystems, regulators of pest and potential pest populations and as contributors to soil quality (ICIPE, 1994). For instance, termites have been shown to markedly influence crop residue breakdown, soil structure development and fertility in some tropical soils (Lobry de Bruyn and Concher, 1990). Ants also modify the soil's physical and chemical properties through their nest building and foraging activities, although often to a lesser extent than the termites or the earthworms (Lobry de Bruyn and Concher, 1990). In a recent review by Duelli and Obrist (1998), ground dwelling spiders have been shown to be good predictors for overall invertebrate biodiversity. The variations of spiders across agricultural spectrum, and their relationships to other groups makes them potentially a useful tool for use in modelling biodiversity (Downie *et. al.,* 1999).

It has been demonstrated that ground beetles (Coleoptera: Carabidae) may serve as natural control agents of agricultural pests. Several carabid species feed on soil insects (Frank, 1971; Best and Beegle, 1977) and others may aid in weed control through seed eating, (Lund and Turpin, 1977). Besides their potential role as biological control agents, carabid populations have enormous potential as biological indicators through response to environmental perturbations (Thiele, 1977). Frietag *et. al.,* (l973) related decreased abundance of ground beetles to the pollution effects of a paper mill while Lavigne and Campron (1978) reported increased numbers of carabids in grassland perturbed by addition of water and nitrogen. Soil insecticides have been shown to have a positive and negative effects on ground beetles (Esau and Peters, 1975; Ghulson *et. al.,* 1978).

The use of assemblages of terrestrial arthropods as ecological indicators is particularly appropriate for evaluating and monitoring habitat reconstruction projects and managed ecosystems (Louda, 1988; Hutcheson, 1990). Several characteristics contribute to the value of terrestrial arthropods as indicators of habitat quality (Wilson, 1987; Andersen, 1990; Kremen, 1994). Insects and their allies represent the greatest morphological and functional diversity in the animal kingdom, playing essential roles as herbivores, pollinators, detritivores, mutualists, predators, parasites, prey for reptiles, birds and mammals (Wilson, 1987; Samways, 1994). Additionally, the short generation times of many taxa can drive dramatic population fluctuations that provide a biological "early warning" of changes in habitat quality and/or ecosystems processes (Wolda, 1988; Southwood *et. al.,* 1979; Andersen, 1990). Also because their population densities are usually extremely high relative to vertebrates, terrestrial arthropods usually can be sampled repeatedly without altering population dynamics (Southwood *et. al.,* 1979; Erwin and Scott, 1980; Williams, 1993). Based on the above morphological and functional qualities, different groups of arthropods have been successfully used as biological indicators in terrestrial and in different agricultural systems. Kromp (1990) used carabid beetles as a bioindicator of farm management in Austrian potato fields and Eyre *et. al.,* (1989) used Carabids and Curculionoids as indictors of grassland management practices.

Ants species have been shown to effectively track environmental gradients (Petal *et. al.,* 1975; Andersen, 1986; Andersen, 1993) in terrestrial as well as agroecosystems. Roth *et. al.,* (1994) looked at the effect of crop management on ant diversity in Costa Rica as did Perfecto (1990) in Nicaragua, and both found associations between ant diversity and vegetative structure and other components of crop management. Lobry De Bruyn (1993) found that certain ants assemblages indicated soil type in farmland and naturally vegetated areas. Delabie and Fowler (1993) found temporal correlation with several environmental factors for ants in Brazilian cocoa plantations, while Tian *et. al.,* (1993) found ant populations were related to the nitrogen content of plant residues placed on soil surfaces to retain moisture and increase heat in tropical agroecosystems. Samways (1981) found a greater number of ant species in citrus orchards that were under biological control than in those where California red scale, *Aonidiella aurantii* (Maskell), was being controlled with insecticides.

Kremen *et. al.,* (1993) argued that terrestrial arthropod assemblages could be used in assessing biodiversity for conservation planning, management and reserve design. Williams (1993) used terrestrial arthropods to explore how effective restoration of wetland forests was, in efforts to restore sites to their original condition after human perturbations.

1.2.3 Diversity of soil dwelling arthropods in diversified agroecosystems

In general, land areas managed for agriculture, forestry and human settlements harbor large number of species (Western and Pearl, 1989; Pimentel *et. al.,* 1992). The underlying reason for this may be that such managed systems tend to maximise biomass, and positive correlation between production and species abundance are commonly recorded (Ward and Lakhani, 1977; Pimentel and Warnake, 1989; Sugden and Rands, 1990). One way of achieving increased biomass in agriculture is through intercropping and agroforestry, and these farming systems have been associated with increases in species numbers (Pimentel *et. al.,* 1992). Recent work has shown that agricultural land with typically high intensities of management, contains some rare species of carabid beetles (Foster *et. al.,* 1997), and spiders (Powell, 1993; Downie *et al.,* 1999) within relatively distinct assemblages compared to less intensively managed habitats. Despite this potential increase in some rare or uncommon species, further studies concerning epigeal spiders have shown that as agricultural management intensity increases, spider diversity decreases (Downie *et. al.,* 1998).

In agriculture, plant species richness and heterogeneity of the environmental factors correlated with diversity of insect populations (Murdock *et. al.,* 1972) are increased by polyculture and by reduced tillage practices. Species composition and structural heterogeneity of the vegetation in agricultural fields can appreciably affect predatory arthropod (ground beetles, spiders, chilopods etc) densities (Smith, 1976; Horn, 1981). A significant increase in predator densities in intercropping systems and other multiplantings as compared to monocultures have been demonstrated by various studies: (Altieri and Whitecomb, 1979; Blomberg and Crossly, 1983; Stinner *et. al.,* 1984).

Agroforestry systems, such as the practice of alley cropping, that integrate crop and tree production are more diverse than traditional cropping systems although not as diverse as most natural forests stands. The combination of trees and crops should provide greater arthropod niche diversity in both time and space than the polyculture of annual crops. The reason being that trees are larger, more complex in their architecture and live longer than herbaceous plants (Lawton, 1978). Several studies have indicated that trees support a significantly more diverse arthropod community than shrubs or herbaceous annuals and perennials (Lawton and Shroder, 1977; Strong and Levin, 1979; Niemala *et. al.,* 1982). These studies attribute this diversity to the structural complexity of trees compared to other types of plants (van Emden and Williams 1974; Lawton, 1978; Southwood, 1978; Strong and Levin, 1979).

Intensification of agriculture towards increased productivity, in some cases, may have adverse effects on soil ecosystems. A good example is mechanical tillage and continuous cropping, which may accelerate soil loss by erosion in some areas. Soil erosion, in turn, can reduce the abundance and diversity of soil biota by physically removing organisms, destroying their preferred microhabitat and changing the microclimate conditions within the soil (Harvey and Pimentel, 1996). Soil loss can also decrease the biodiversity of soil biota by removing leaf litter and organic matter, thereby creating a less hospitable environment for many soil organisms (Milton *et. al.,* 1994).

1.2.4 Justification and significance of the study

Agricultural management practices are generally developed with the goals of maximizing the productive biota (crops and livestock), eliminating the destructive biota (weeds pests and pathogens) and often with less specific intent, maintaining the resource biota (cover -crops, decomposer and detritivore organisms and natural enemies of agricultural pests) (Beare *et. al.,* 1997). However, the effect of these usually diverse intensified agroecosystems to arthropod diversity is not well understood, mainly because conservationists have greatly ignored agroecosystems, while most of the research work has been for a long time, directed towards the so called undisturbed systems like the natural forests.

Until recently, efforts to preserve biodiversity have focused on natural systems, despite the fact that these areas make up only about 5% of the terrestrial environment (Western and Pearl, 1989). This focus on undisturbed habitats has been challenged and attention has been called to the fact that 95% of contemporary terrestrial ecosystems are managed ones, including agricultural systems (50%) and commercial forestry (20%) (Western and Pearl, 1989). Given this pattern, there is increasing recognition that most species interact with agricultural systems, even if their primary habitat is in natural areas. Moreover, a large proportion of the total species of a region are likely to be found in agroecosystems (Pimentel *et. al.,* 1992). The management of these agricultural systems can dramatically affect overall levels of biodiversity, as well as the success of particular species.

Although our knowledge of the biodiversity of organisms in all soils is shamefully poor, soils in the tropics deserve particular attention for a number of reasons. The majority of research has concentrated on soils of temperate regions, yet there is evidence that biodiversity of soil invertebrates is greater in the tropics than at greater distances from the equator (Swift *et. al.,* 1979).

The effects of multiple cropping on ground dwelling arthropod populations have been studied largely using temperate ground beetles (e.g. Brust *et. al.,* 1986; Perfecto *et. al.,* 1986; Ca'rcamo and Spence, 1994). Comparable studies are lacking for tropical polycultural systems especially in an agroforestry context. While most of the research work in agroforestry is concentrated on its potential in proper soil management, comparative studies on its potential in maintaining a high arthropod diversity are lacking especially in Tropical Africa.

This study was intended to contribute towards evaluating relationships in agroecosystems and to assess the impacts of various cropping systems on the diversity of soil dwelling arthropods and possibly to identify a system that would yield to a high productivity and at the same time conserve environmental integrity.

1.2.5 Hypotheses

Agricultural diversification through alley cropping increases the diversity of ground dwelling arthropods.

1.2.6 Objectives of the study

1.2.6.1 Overall objective

To investigate the effect of alley cropping, mulching, intercropping and pesticide use on the diversity and dynamics of ground dwelling arthropods.

1.2.6.2 Specific objectives

1. To determine ground dwelling arthropod species associated with the cropping systems and unmanaged field systems in the study.

2. To establish the effects of alley cropping, intercropping mulching and pesticide use on the diversity and dynamics of ground dwelling arthropod communities.

CHAPTER TWO

2.0 MATERIALS AND METHODS

2.1 Description of the study site

This study was conducted at the Kenya Agricultural Research Institute (KARI) Regional Centre at Mtwapa, Coast Province, Kenya (3° 56’ S, 39° 44’ E and 15m above sea level, (Figure 1). At the coast, soils are generally sandy and deficient in nutrients, especially nitrogen and phosphorous (Warui and Kuria, 1983). Average rainfall is about 1200 mm per year, which tends to decrease towards the North and interior. Rainfall is bimodal, allowing the cultivation of two crops annually, a long cropping season from April to June and an often unreliable short cropping season from October to December. Temperatures are generally high (25°–30°C) throughout the year (Warui and Kuria, 1983).

Agriculture in the coastal strip is characterized by predominantly tree–based systems in which trees such as coconut, palms, cashews and mangoes are intercropped with cassava and/or maize with or without livestock grazing. Alley cropping may be an alternative farming system (Macklin *et. al.*, 1989).

2.2 Experimental Design and Plot-layout

Five month old seedlings (nursery-reared) of *Leucaena leucocephala* (Lam) de Wit and *Gliricidia sepium* were planted on experimental plots measuring 16 x 13m.at a spacing of 3.2m between and 0.65m within hedgerows with a 4m buffer strips. Alternating rows of maize and cowpea were planted. Experimental plots consisted of two plots of leucaena only, one plot of gliricidia only, two plots of alternating rows of leucaena and gliricidia plants within hedgerows, one plot of alternating leucaena and gliricidia plants within hedgerows, and six plots without trees. This gave a total of twelve treatments laid down in a randomized complete block design and replicated four times. An adjacent unmanaged field that has been lying fallow for the last approximately 20 years was also sampled for comparison with the managed plots. It consisted of tall old cashewnut trees and bushes. Since it was the immediate adjacent unmanaged piece of land, it was used as a reference site (Wolda 1988) which statistically is one of the controls.

During the cropping seasons associated with long rains (May-August 1999), short rains (November 1999-February 2000), long rains (May-August 2000) and short rains (October 2000-February 2001), maize (Pwani Hybrid 4) was planted between the hedgerows at a spacing of 30cm within rows, 80cm between rows of maize and the tree hedgerows. In two of the leucaena-gliricidia hedgerow plots, a row of cowpea (var. K 80) was planted between the rows of maize (and not between the maize and the trees) at an inter- row spacing of 30cm. Three of the plots without trees were planted to maize alone while the others were planted to an intercrop of maize and cowpea. Two plots were planted to cowpea alone.

Two days before planting maize and cowpea, the leucaena and gliricidia trees were pruned to 30cm above the ground level and all foliage for respective plant species applied as mulch on respective plots. Foliage from a separately developed tree plantation was used to mulch plots without trees, except for one of the maize monocrop plots. Maize from one of the two mulched maize monocrop plots and one of the two leucaena+maize plots was fully protected from stem borers using weekly granular insecticide application of Bulldock™ (betacyfluthrin) from one week after plant emergence to crop maturity. One of the cowpea monocrop was treated with furadan to protect the crop from pests. A summary of experimental plots is given as Table 1 (1999-2000) and Table 2 (2000-2001).

2.3 Pitfall trapping of ground dwelling arthropods

Ground dwelling arthropods were sampled by use of pitfall traps, which has long been an accepted and convenient method of sampling soil arthropods (Greenslade, 1964; Southwood, 1978). It is an effective and cheap way of quantitatively surveying the ground surface–active arthropods, and allows for comparison of assemblages in different habitats.

Plastic cups measuring about 11cm in diameter and 8cm high were half-filled with Ethyl glycol and sunk into the ground so that the mouth was level with the ground. Some liquid detergent was added into the pitfalls to break the surface tension. Round mouth traps were used since they are not subject to any directionality in sampling (Luff, 1975). The pitfalls were also roofed by lids supported on pegs (Plate 4) which serve to keep out debris and prevent the entry of animals and precipitation from above (New, 1998).

Three pitfall traps per plot were laid at the middle of each plot forming a triangular arrangement at a distance of 5.3m apart from each other and from the edges of the plot. Traps were left in the field for one week after which they were removed by hand and replaced with a new set of traps. The contents of the traps were collected by straining the preservative through a fine mesh and rinsing the contents of the strainer into a specimen bottle (vial) containing 70% alcohol and preserved for identification. Sampling commenced from two weeks after crop germination. During the first two seasons (1999-2000) sampling was carried out only during the cropping period, that is as long as there was crop in the fields (June - August 1999 and December - February 2000). In the 2000-2001 seasons, sampling continued from two weeks after germination (June 2000) to one month after harvesting (September 2000) and then commenced again two weeks after germination in the second season (December, Short rains) to harvesting (February 2001).

2.4 Arthropods Identification

Sorting and identification of all the arthropods was carried out at the Department of Entomology and Invertebrate Zoology of the National Museums of Kenya with the help of qualified staff. Arthropods collected during the cropping seasons of 1999-2000 were identified to family level. During the cropping seasons of 2000-2001 only five Orders representing the most abundant and important groups in the sample were considered for further identification based on their abundance in the samples and their significance in agroecosystems. These are Orthoptera (Crickets), Coleoptera (Beetles), Hymenoptera (Ants), Blattoidea (Cockroaches) and Aranae (Spiders). The orders were identified to Genus and in some cases to species level, except for Aranae, which could not be identified further as there were no local experts. Since the Order Coleoptera had the largest number of representatives at species level, all the subsequent studies at this level were limited to this Order.

2.5. Data management and Analysis

Data obtained from the pitfalls were pooled and averaged for each plot. The following species indices were calculated using the methods described by Krebs (1989), using program diverse (version 5.1):

- **S** - Species richness, the total number of species present;

- Shannon-Wiener diversity index, expressed as;

  H'$=\sum pi$ (log pi.),

  Where pi is the proportion of the i^{th} species in the sample

- Simpson–Yule diversity index, expressed as;

  D$=1/\sum pi^2$

  Where pi is the proportion of the i^{th} species in the sample

- Evenness, a measure of relative abundance expressed as;

  J=H'/ log S.

  Where S is the species richness and H' is the Shannon Wiener diversity index

- Dominance

  $$d = \frac{\text{Total number of individuals}}{\text{Total number of individuals of all species}}$$

D and H' indexes are important in estimating the species diversity of communities based on the number of species (S) present in each community as well as the number of individuals representing each species (n). These indices make use of both the number of species collected and the total number of individuals collected. I used Shannon index because it is ubiquitous in the literature, and one can use parametric statistics to test for significant differences between surveys. The Simpson's index was used because it is considered a dominance measure, being weighted towards the abundance of the commonest species in the community while the Shannon Wiener index takes into consideration the rare species in the community.

The data obtained (S, D, H' and J indices per treatment) was then subjected to analysis of variance (ANOVA) (PROC. GLM, SAS. Institute, 1999-2000). Thereafter, pre-planned orthogonal comparisons were made to test for the effects of maize monocrop versus cowpea intercropping mulched versus unmulched, pesticide versus no pesticide, hedgerow versus no hedgerow intercropping, Leucaena versus Gliricidia, alternating tree rows versus alternating tree plants, maize versus cowpea and managed versus unmanaged. This procedure was repeated for the ground beetles alone (Coleoptera) to determine the effects of cropping systems on species richness, diversity and evenness of these beetles.

Abundance data was transformed using square root transformation and treatment differences for spiders and the dominant Coleoptera families obtained using analysis of variance (ANOVA) (PROC. GLM, SAS. Institute, 1999-2000) followed by pre-planned orthogonal contrasts as explained above. Overall community and population dynamics over time were illustrated by plotting abundance data against time (in weeks). Similarity of arthropod community assemblages in different plots was obtained by use of Cluster analysis (PROC. Cluster Analysis, SAS. Institute, 1999-2000) and illustrated in form of a dendrogram. Clustering was based on species presence and absence as well as numbers in different treatments, to find out which treatments were closely related and those that were not related at all based on their community structure.

Table 1: SUMMARY OF TREAMENTS (1999-2000)

Hedgerow Type	Crop (s) between Hedgerows
Leucaena	maize
Gliricidia	maize
Alternating rows of Gliricidia and Leucaena	maize, cowpea
Alternating rows of Gliricidia and Leucaena	maize
Alternating Leucaena and Gliricidia plants within hedgerows	maize, cowpea
Non	maize, cowpea
Non	maize
Non	maize+pesticides
Non	maize- no mulch
Leucaena	maize
Unmanaged System	

Table 2: SUMMARY OF TREAMENTS (2000-2001)

Hedgerow Type	Crop (s) between Hedgerows
Leucaena	maize
Gliricidia	maize
Alternating rows of Gliricidia and Leucaena	maize, cowpea
Alternating rows of Gliricidia and Leucaena	maize
Alternating Leucaena and Gliricidia plants within hedgerows	maize, cowpea
Non	maize, cowpea
Non	maize
Non	maize+pesticides
Non	maize- no mulch
Non	cowpea
Non	cowpea+p
Leucaena	maize
Unmanaged Systems	

Plate 1: Maize intercropped with Leucaena

Plate 2: Maize intercropped with Cowpea, Leucaena and Gliricidia

Plate 3: The unmanaged system in the background

Plate 4: Pitfall trap

CHAPTER THREE

3.0 RESULTS AND DISCUSSION

3.1 RESULTS

3.1.1 Relative abundance of ground dwelling arthropods

A total of 8,184 arthropods were collected during the long and short rains of 1999-2000 belonging to 12 families (Table 3a). There were five major Orders in the samples, namely Aranae, Hymenoptera, Coleoptera, Orthoptera and Isoptera. The family Formicidae (Hymenoptera) was the most abundant accounting for 84.38% (Table 3b). Other Orders present in the samples included Diplopoda, Chilopoda, Oligochaeta and Isopoda. Out of the 15 families identified from the 1999-2000 samples, 9 of them belonged to the Order Coleoptera.

During the long and short rains of 2000-2001 a total number of 146, 958 individuals were collected belonging to the five major Orders in the sample, namely Hymenoptera, Coleoptera, Orthoptera, Blattoidea and Aranae. Other Orders present in the samples were not identified further due to limited time and the magnitude of the samples collected. A total number of 70 species were identified belonging to 24 families (Table 4a). Out of these, 18 families belonged to the Order Coleoptera while the family Formicidae (Ants), the only ground dwelling group in the Order Hymenoptera was the most abundant, accounting for 78.44% of the arthropods collected in that season (Table 4b). There were seven species of the family Formicidae with *Dorylus nigricans* being the most abundant accounting for over 90% of insects in this family. Among the Coleoptera, the family Scarabaeidae (dung beetles) was the most diverse being represented by 9 species. Three species of family Gryllidae (Crickets), the only family representing the Order Orthoptera in the samples were identified. *Gryllus spp.* was the most abundant in this Order. Also present was the Order Blattoidea (Cockroaches) which was represented by three families, the dominant species being *Blatella germinica* and *Blatta orientalis*, both of which belong to the family Blatellidae.

3.1.2 Effect of cropping systems on relative abundance of spiders (Aranae) and some beetle (Coleopteran families)

The unmanaged fields recorded the highest mean relative abundance of spiders (Aranae, n=19.45), ground beetles (Carabidae, n=6.99), and rove beetles (Staphylinidae, n=6.73) all of which are predominantly predatory species (Table 5). The relative abundance of these families was lowest in the unmulched plot (m-mu) and maize monocrop treated with pesticides (m+p). On the other hand families that contain predominantly herbivorous species were most abundant in the maize monocrop plots with pesticides (m+p). The highest abundance of Sap beetles (Nitidulidae), an important pest, was recorded in the maize monocrop treated with pesticides (m+p), while the lowest abundance was observed in the treatments with the greatest plant species diversity (mlgc*, n=3.02). The maize treated with pesticides also recorded a high population of click beetles (Elateridae, n = 8.97), while the lowest abundance of these beetles was recorded in the unmanaged plots (UM, n = 4.36). However dung beetle populations were highest in the unmanaged system and lowest in the maize intercropped with cowpea (Scarabaeidae, n=7.06 and 2.31, respectively).

3.1.2.1 Effect on the predatory arthropod groups

There were significant differences between treatments in the mean relative abundance of predatory arthropod groups: Aranae (P=0.0141), Carabidae (P=0.0162), and Staphylinidae (P=0.0038). All the cropping systems significantly reduced spider (Aranae) and ground (Carabidae) beetle abundance (Table 6) compared to the unmanaged plot (UM). This was with the exception of the maize intercropped with leucaena and gliricidia (mlg) and the cowpea (c) treatments, whose spider, and ground beetle abundance was not significantly different (P>0.05) from that of the unmanaged plot (UM). Intercropping maize with agroforestry tree species and cowpea increased the abundance of spiders but this increase was not significant. It is also worth noting that the abundance of dung beetles in the plots with alternating rows of leucaena and gliricidia was significantly lower than that of the plots with alternating plants of these tree species within rows (mlgc n=2.39, mlgc* n=4.46, P=0.0334). Intercropping maize with cowpea significantly increased the relative abundance of rove (Staphylinidae) beetles compared to the maize monocrop ((mc n=4.54, m n=2.63, P=0.0108) (Table 6).

3.1.2.2 Effect on the herbivorous arthropod groups

Among the herbivorous species significant treatment differences in relative abundance were observed for Curculionidae (Weevils, P=0.04), Elateridae (Click beetles, P=0.0291), Scarabidae (dung beetles, P = 0.0012) and Nitidulidae (Sap beetles, P=0.0362). A significant increase in the abundance of weevils (Table 6) was observed in the plots treated with pesticides compared to the unmanaged plot (m+p=3.37, ml+p=3.27, UM=1.99, P=0.029). Interestingly, maize intercropped with gliricidia recorded a significantly lower numbers of weevils than that intercropped with leucaena (mg=2.55, ml=3.81, P=0.04). Although there was no overall significant difference between treatments in the number of darkling beetles (Tenebrionidae, P>0.05), intercropping maize and cowpea significantly increased the abundance of these beetles (mc=12.04, m=8.65, P=0.0142). The intercrop of maize and gliricidia only, had a significantly lower abundance of darkling beetles compared to that of maize and leucaena only, and maize intercropped with all the four crops (mg n=6.19, ml n=10, mlgc n=9.33, P=0.0223).

3.1.3 Dominance (d), community and population dynamics of some ground dwelling arthropods

Different arthropod communities seemed to be dominant in different treatments at different times of the seasons. Out of the 70 different species identified in this study, 23 of them were present in all the treatments and thus recognized as common species. The rest were rare species only present in some treatments and not in others, while some species were seen to be confined to some specific treatments. For instance, two Coleoptera species, *Scholtzi spp.* (Scarabidae) and *Sphenoptera spp.* (Buprastidae) were only present in treatments with cowpea. *Carpophilus spp.* (Nitidulidae) was absent in the maize intercropped with cowpea (mc) treatments but present in all the other treatments.

The dominant species in all the treatments was *Gonocephalum simplex* (Tenebrionidae) (Table 7). While *Meristhus lepidotus* (Elateridae) was the second dominant species in all the cropping systems except for the plots with maize intercropped with leucaena (ml). In these plots (ml) as well as in the unmanaged plots (UM), *Abacetus spp.* (Carabidae) was the second most dominant (Table 7). A number of species that were rare in the cropping systems were seen to be more common in the unmanaged systems. They include *Holosus spp.*, *Ornthophagus omostigma* and *Philonthus spp.*, all of which belong to the family Staphylinidae and are predatory species.

The dynamics of different arthropod families followed different trends in response to cropping seasons. The number of weevils (Curculionidae) remained more or less constant with their relative abundance remaining at below 25 individuals per weekly samples throughout the sampling period (Figure 2 - 5). The number of ground beetles decreased sharply at the beginning of the sampling period never to reach the original population size again, but rather remaining more or less constant during the rest of the sampling period. The number of sap beetles and click beetles underwent a steady increase during the first cropping season, followed by a sharp increase towards the end of this season (August 2000). Thereafter there was a sharp decrease in numbers after harvesting (inter - season period), a response also observed in almost all of the other Coleoptera families studied. During the second cropping season, there was a sharp increase in numbers of arthropods at the beginning of this season in the month of December (2000).

At the beginning of the first cropping season (June 2000), *Abacetus spp.* was the most dominant (d =31.52%), followed by *Ornthophagus omostigma* (d = 7.06%) (Table 8). Thereafter, *G. simplex* and *Nudobius cephalus* (Staphylinidae) became the most dominant species until harvesting (end of first season). During the period in between the first and the second season, *M. lepidotus* and *Brachypeplus spp*. (Nitidulidae) were the most dominant species. *G. simplex* continued to dominate throughout the rest of the first as well as the whole of the second season, with its abundance and dominance increasing with time (Table 8). In the second cropping season, *M. lepidotus* was the second dominant species during the early crop stages, and it was replaced by *Taraxides panctatus* (Elateridae) for the rest of the season (Table 8). *Carpophilus spp.* was not observed at all during the months of July and December 2000 (beginning of the first season) and February 2001 while *Holosus spp.* and *N. cephalus* were absent during the month of February 2001 (Table 8).

Community assemblages of all the arthropods present in all the treatments throughout the sampling period differed according to the management practices in different treatments as revealed by the cluster analysis (Figure 6). There were two major clusters one made up of all the cropping systems and the other by the unmanaged systems. The cropping systems were grouped into three clusters. The first cluster consisted of ml, mlgc, ml+p and m+p, the second mg, mlg, m and m-mu, while the third consisted of mlgc* mc, c+p, and c. The closest treatments based on species assemblages were ml and mlgc, mlg and m, and c and c+p. This grouping implies that intercropping maize did not cause a significant alteration of the arthropod community assemblages and so did use of pesticides in cowpea treatments. The maize monocrop treated with pesticides was grouped in the same cluster with the maize-leucaena treatment treated with pesticides and this cluster was the cluster that was furthest (very different) from the unmanaged. The cluster consisting of the maize intercropped with cowpea and maize intercropped with cowpea (mc) and agroforestry tree species (mlgc*) was the one closest (not very different) from the unmanaged.

3.1.4 Effect of cropping systems on species richness, diversity and evenness of ground dwelling arthropods

During the 1999-2000 cropping seasons, the intercrops had higher species richness (S) and diversity than the monocrops. (Table 9). The highest species richness was recorded in the maize intercropped with cowpea treatments (S = 8.5) followed by the unmanaged (UM) and the plots with alternating rows of leucaena and gliricidia intercropped with maize and cowpea (mlgc) (S = 8.25 for both UM and mlgc treatments). Plots in which pesticides were applied (m+p, S = 6.75, ml+p, S = 6) as well as the unmulched maize monocrops (m-mu, S = 6.75) recorded the lowest species richness. The highest species diversity was recorded in the unmanaged plots (UM, H' = 0.551) and maize intercropped with gliricidia plots (mg, D = 2.762). Treatments treated with pesticides had low species diversity (ml+p, H' = 0.288 and D = 1.66). However, in all of the cases above, means of S, H' and D were not statistically different between treatments ($P>0.05$). There was however a highly significant difference in Evenness (J), between treatments with the ml, mg and UM having greater evenness than all the other treatments (J = 0.736, 0.618 and 0.594 respectively, $P<0.0001$).

During the 2000-2001 cropping seasons, the unmanaged fields (UM) recorded the highest species richness (S=28.5) while maize monocrop with pesticide (m+p) recorded the lowest (S=24) (Table 10). Species richness (S) for all the ground dwelling arthropods was however not significantly different between treatments (P>0.05, Table 10). Despite this lack of overall treatment differences in species richness, orthogonal contrasts indicated significant differences between the unmanaged treatments and the maize monocrop with and without pesticides (UM S=28.5, m S=24.5, m+p S=24, P=0.04, Table 12). I also looked at treatment differences in Species richness (S) among the ground dwelling beetles (Coleoptera). The unmanaged fields recorded the highest number of species (UM S=20.75), while the least was recorded in the maize monocrop treated with pesticides (m+p S=16.5). There was however no significant difference in species richness between treatments (P>0.05, Table 11).

Species diversity as measured by Shannon Weiner (H') and Simpson Yule (D) diversity indexes as well as evenness (J) were significantly different between the treatments (H', P=0.002, D, P<0.0001 and J, P<0.0001, Table 10b). The unmanaged fields (D=9.76, H'=3.75 and J=0.32, Table 10) and the plots with agroforestry tree species [mlg (D=8.06, H'=3.48 and J=0.28), mlgc*(D=7.99, H'=3.53 and J=0.29) and mlgc (D=7.89, H'=3.44)] recorded the highest species diversity and evenness. The lowest diversity was observed in the plots without mulch (m-mu, D=4.81) and in the plots treated with pesticides (ml+p, H'=2.86), while the lowest evenness was observed in the cowpea monocrops (c, J=0.2) (Table 10).

All the cropping systems in this study significantly reduced arthropod diversity (D Index) compared to the unmanaged plot (UM), with the exception of the treatments with alternating plants of both agroforestry tree species between rows intercroped with maize and cowpea (mlgc*). The latter (mlgc*) recorded a lower diversity than that of the unmanaged plot but this difference was not significant (UM D=9.76, mlgc* D=7.99, P>0.05, Table 12). Compared to the control, H' Index was also significantly reduced in all the cropping systems without agroforestry tree species except the maize, leucaena and gliricidia intercrop (mlg H'=3.48) as well as the agroforestry plots with pesticides (ml+p H'=2.86). In both of these two exceptions, H' was significantly lower than the unmanaged (control) plots (UM H'=3.75, P=0.0239 and P<0.0001 respectively) (Table 12). Evenness was greater in the control compared to all the other treatments. However this difference was not significant between the control (Unmanaged) and the treatments with agroforestry tree species, specifically, mlgc* and mg (P>0.05). Also worth noting is the high diversity and evenness observed in the treatments with alternating leucaena and gliricidia plants within rows (mlgc* H'=3.53 and J=0.29), which was statistically different (P=0.0034) from that of the plots with alternating rows of the two agroforestry tree species (mlgc H'=3.44 and J=0.24) (Table 11).

3.1.5. Effect of cropping systems on species richness, diversity and evenness of ground dwelling beetles (Coleoptera)

Species diversity and evenness of ground dwelling beetles (Coleoptera) followed a trend almost similar to that of the overall ground arthropods. Once more the unmanaged fields (UM) recorded the highest species diversity and evenness (D=8.6, H'=3.59 and J=0.47, Table 11). The maize monocrop with and without mulch both recorded the lowest diversity as measured by Simpson Yule diversity index (D=3.53). Similarly the maize monocrop with pesticide recorded the lowest diversity as measured by Shannon Weiner diversity index (H'=2.48) and evenness (J=0.26) (Table 11). Although species diversity was higher in the unmanaged plots than in all the cropping systems, this difference was not significant between some of the treatments with agroforestry trees species (UM, D=8.6, mg D=7.37 P=0.1075, H'=3.28 P=0.086 and mlgc* D= 8 P=0.4122, H'=3.46 P=0.4553). A comparison of species diversity between treatments with alternating leucaena and gliricidia plants within rows (mlgc* H'=3.46, D=8) with that of the plots with alternating rows of the two agroforestry tree species (mlgc H'=3.09, D=5.46) indicated a highly significant difference (P<0.0001) with the mlgc* being more diverse than the mlgc (Table 12).

All cropping systems had a significantly low evenness of ground beetles compared to that of the unmanaged plots (UM). However this difference was not found to be significant when compared with some of the treatments with agroforestry tree species (UM J=0.47, mg J=0.4, mlgc* J=0.43, P>0.05). Among the cropping systems, evenness was significantly lower in the treatments with alternating leucaena and gliricidia plants within rows than in the plots with alternating rows of the two agroforestry tree species (mlgc* J=0.43, mlgc J=0.53, P=0.001) (Table 12).

Figure 1: Study site: Location of Mtwapa KARI Station

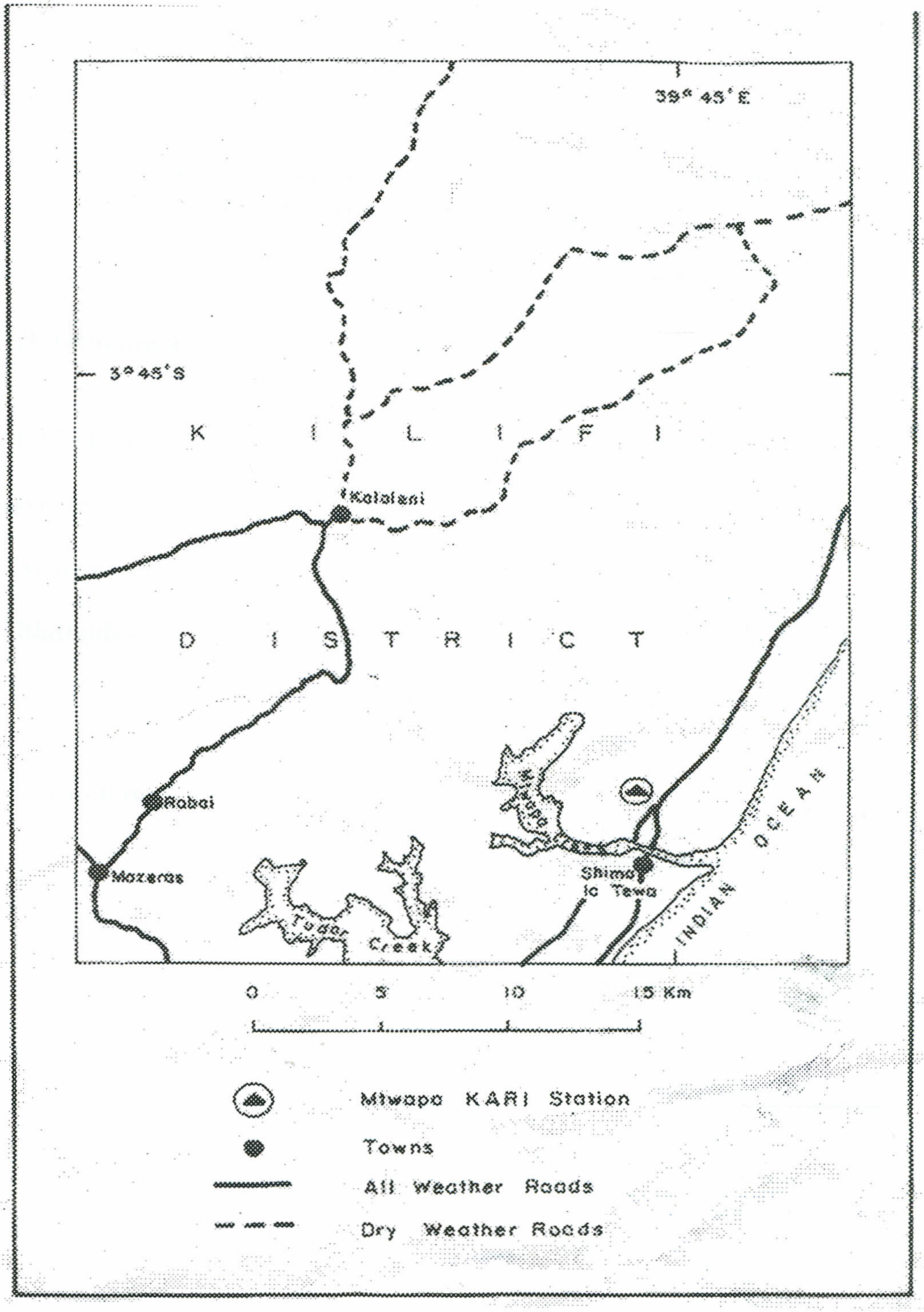


Table 3a: Summary of arthropod Orders and Families associated with the 1999-2000 cropping seasons at Mtwapa.

Order	Family
Hymenoptera	
	Formicidae
Orthoptera	Gryllidae
Isoptera	
Aranae	
Blattoidea	
	Blattidae
Coleoptera	
	Carabidae
	Staphylinidae
	Tenebrionidae
	Anthicidae
	Elateridae
	Nitidulidae
	Scarabidae
	Bostrichidae
	Cicindellidae

Table 3b: Relative abundance (%) of arthropods associated with the 1999-2000 cropping seasons at Mtwapa.

Family	% Relative abundance
Aranae	2.309
Blattidae	0.012
Carabidae	1.686
Elateridae	0.904
Nitidulidae	1.417
Tenebrionidae	0.268
Gryllidae	6.048
Formicidae	84.384
Others	2.972

Table 4a: Summary of arthropods collected in the 2000-2001 Cropping systems at Mtwapa

Order and Family	Genus species
Blattoidea	
Blaberidae	*Fusca spp.*
	Perisphaeria spp.
Blattellidae	*Blattella germinica*
	Bllatta orientalis
	Deropettis erythrocephala
	Deropettis spp.
	Ectobius spp.
Blattidae	*Periplaneta americana*
Bllaberidae	*Bllaraphadora spp.*
Coleoptera	
Carabidae	
	Abacetus spp
	Abacetus spp
	Cliuina mandibularis
	Taraxides panctatus
	Tetragonderus babaulti
Chrysomelidae	*Chaetocnema spp.*
	Diobrotica spp.
	Medythia quaterna
	Ootheca bennigseni
	Lema spp.
	Alticia spp.
Cicindelidae	*Cicindella spp.*
Curculionidae	*Cnemacamptus viridanus*
	Nematocerus spp.
	Systates amplicollis

Table 4a: Continued

Order and Family	**Genus species**
Elateridae	*Brachypeplus spp* *Drasterius aethiopicus* *Meristhus lepidotus* *Tylotarsus spp.*
Lagriidae	*Lagria villosa*
Meloidae	*Elatica spp.* *Epicauta albovittata* *Mylabris holocericea*
Myctophagidae	*Typhaea stecorea*
Nitidulidae	*Spp#1* *Brachypeplus spp* *Spp#2* *Carpophilus spp* *Urophus humeralis*
Pselaphidae	*Pselaphus helsei*
Scarabaeidae	*Ornthophagus omostigma* *Orphinius spp.* *Scarabaeus scholtzi* *Schizonyucha spp.* *Anachalcos convexus* *Copris plutus* *Spp #1* *Spp #2* *Spp #3*
Staphylinidae	*Holosus spp* *Nudobius cephalus* *Paederus littorarius* *Philonthus spp* *Pinophilus strictus*

Table 4a: Continued

Order and Family	**Genus species**
Tenebrionidae	*Gonocephalus simplex*
	Homalopsis Prosternalis
	Taraxides pactatus
	Tenebrios spp.
	Tylotarsus spp
Others	
Anobiidae	
Anthicidae	
Buprastidae	
Byturidae	
Ceratocanthidae	
Hymenoptera	
Formicidae	*Camponatus spp.*
	Cataulaeus spp.
	Dorylus nigricans
	Messor spp.
	Paltothyreus spp.
	Paltothyreus tarsatus
	Tetramorium spp.
Orthoptera	
Gryllidae	*Gryllotalpa spp.*
	Gryllus spp
	Phaeophilacris spp.
Aranae	

Table 4b: Relative abundance (%) of arthropods associated with the 2000-2001 cropping seasons at Mtwapa.

Order	% Relative abundance
Aranae	6.611
Blatellidae	1.117
Carabidae	0.862
Elateridae	1.665
Nitidulidae	0.948
Tenebrionidae	2.527
Gryllidae	6.316
Formicidae	78.436
Others	1.518

Table 5: Mean relative abundance ± S.E. of Spiders (Aranae) and some selected beetle (Coleoptera) families during the SR and LR of 2000- 2001 cropping seasons at Mtwapa

Treatments	Aranae	Coleoptera	Carabidae	Curculionidae	Elateridae	Nitidulidae	Scarabaeidae	Staphylinidae	Tenebrionidae
1. ml	15.1 ± 0.45	16.15 ± 1.13	5.08 ± 0.39	3.81 ± 0.41	7.38 ± 0.96	6.22 ± 1.05	2.79 ± 0.27	3.73 ± 0.53	10 ± 0.71
2. mg	14.16 ± 0.54	12.74 ± 1.24	5.17 ± 0.28	2.55 ± 0.4	5.68 ± 0.81	5.11 ± 1.03	2.50 ± 0.57	4.41 ± 0.96	6.19 ± 0.76
3. mlgc	15.51 ± 1.20	15.02 ± 1.20	4.47 ± 0.32	2.71 ± 0.61	7.52 ± 1.41	5.68 ± 0.63	2.39 ± 0.09	3.18 ± 0.37	9.33 ± 0.67
4. mlg	14.94 ± 1.23	13.70 ± 1.04	4.92 ± 0.71	2.79 ± 0.26	5.63 ± 0.29	4.16 ± 1.14	3.41 ± 0.35	3.61 ± 0.81	8.59 ± 0.86
5. mlgc*	15.51 ± 0.70	14.81 ± 0.44	4.62 ± 0.48	2.25 ± 0.24	6.24 ± 0.32	3.02 ± 0.33	4.46 ± 1.61	4.04 ± 0.56	9.38 ± 0.34
6. mc	15.72 ± 1.36	16.49 ± 1.75	5.43 ± 0.41	2.36 ± 0.37	6.91 ± 1.53	3.16 ± 0.50	2.31 ± 0.84	4.54 ± 0.46	12.04 ± 1.36
7. m	15.16 ± 1.03	13.75 ± 1.33	4.64 ± 1.04	2.30 ± 0.40	6.54 ± 0.48	5.07 ± 1.11	2.65 ± 0.39	2.63 ± 0.32	8.65 ± 0.71
8. m+p	14.65 ± 0.96	16.17 ± 0.86	3.54 ± 0.66	3.37 ± 0.66	8.97 ± 0.76	7.81 ± 1.61	2.29 ± 0.28	2.59 ± 0.41	8.53 ± 0.76
9. m-mu	13.28 ± 0.25	14.20 ± 0.96	4.73 ± 0.18	2.27 ± 0.45	6.84 ± 0.70	4.72 ± 1.18	3.78 ± 0.70	3.38 ± 0.35	8.54 ± 0.34
10. ml+p	15.15 ± 0.85	15.03 ± 0.92	5.15 ± 0.40	3.27 ± 0.34	6.41 ± 0.39	5.68 ± 1.18	3.01 ± 0.84	3.72 ± 1.06	8.97 ± 0.79
11. UM	19.45 ± 1.45	16.86 ± 1.38	6.99 ± 0.73	1.99 ± 0.71	4.36 ± 0.71	3.57 ± 0.49	7.06 ± 0.85	6.73 ± 0.64	9.28 ± 1.07
12. c+p	15.10 ± 1.14	15.06 ± 0.72	4.77 ± 0.09	1.60 ± 0.56	8.18 ± 0.77	3.57 ± 0.50	2.72 ± 0.21	5.07 ± 0.72	9.13 ± 0.67
13. c	12.53 ± 1.2	16.62 ± 0.78	6.09 ± 0.36	2.09 ± 0.35	8.34 ± 0.73	6.03 ± 0.68	3.42 ± 0.30	5.05 ± 0.63	9.24 ± 0.75
Probability	**0.0141**	**<0.0001**	**0.0162**	**0.04**	**0.029**	**0.036**	**0.0012**	**0.0038**	0.067

P = 0.05

m - Maize, **l** - Leucaena, **g** - Gliricidia, **c** - Cowpea, **p** - Pesticides, **mu** - Mulch, **UM** - Unmanaged, **mlgc** - Alternating rows of Leucaena and Gliricidia, **mlgc*** - Alternating Leucaena and Gliricidia plants with the rows, **SR** - Short rains, **LR** - Long rains

Table 6: Probabilities of orthogonal contrasts on relative abundance of spiders (Aranae) and some beetle (Coleoptera) families during the SR and LR of 2000-2001 cropping seasons at Mtwapa

Treatment Contrasts	Aranae	Carabidae	Curculionidae	Elateridae	Nitidulidae	Scarabidae	Staphylinidae	Tenebrionidae
m vs. mc	0.6952	0.2948	0.9193	0.7611	0.1636	0.7327	0.0426	0.0142
c vs. mc	0.9677	0.8646	0.2594	0.1758	0.2708	0.9499	0.0108	0.7148
Mg vs. mlgc	0.3495	0.3476	0.7887	0.1314	0.6711	0.9112	0.1829	0.0223
ml vs. mlgc	0.7760	0.4158	0.0811	0.909	0.6934	0.6862	0.5448	0.6226
Mlg vs. mlgc	0.6934	0.5435	0.9007	0.1217	0.2671	0.3013	0.6346	0.5776
Mlg vs. mlgc*	0.9745	0.6843	0.3798	0.3135	0.4046	0.2856	0.6429	0.334
ml vs. mg	0.5129	0.8987	0.046	0.1618	0.4144	0.7697	0.4606	0.0065
Mlgc vs. mlgc*	0.5679	0.2815	0.8561	0.5789	0.9212	0.0334	0.583	0.1109
m vs. m+p	0.0795	0.083	0.4249	0.8914	0.0758	0.4703	0.9863	0.9375
c vs. c+p	0.7249	0.1439	0.0869	0.0477	0.0498	0.7143	0.9696	0.9314
m vs. m-mu	0.1967	0.9009	0.9539	0.8045	0.7943	0.2542	0.4192	0.9359
m vs. c	0.9677	0.8646	0.2594	0.1758	0.2708	0.9499	0.0108	0.7148
UM vs. ml	0.0038	0.0141	0.005	0.0151	0.0572	<0.0001	0.0021	0.5966
UM vs. Mg	0.0006	0.0192	0.3678	0.2713	0.2933	<0.0001	0.0149	0.0244
UM vs. mlgc	0.0080	0.0016	0.2447	0.0114	0.1261	<0.0001	0.0004	0.9702
UM vs. mlg	0.9144	0.8363	0.0581	0.0385	0.6622	0.4789	0.1171	0.6833
UM vs. mlgc*	0.0025	0.0028	0.678	0.1212	0.6874	0.011	0.0053	0.6522
UM vs. mc	0.0116	0.0424	0.5514	0.0383	0.7613	<0.0001	0.0211	0.0436
UM vs. m	0.0042	0.003	0.6207	0.0737	0.2721	<0.0001	<0.0001	0.6331
UM vs. m+p	0.0016	<0.0001	0.0298	0.0004	0.0032	<0.0001	<0.0001	0.5735
UM vs. m-mu	<0.0001	0.0043	0.6619	0.0435	0.3998	0.0017	0.0007	0.5773
UM vs. ml+p	0.0041	0.0178	0.0444	0.0927	0.1258	0.0002	0.0021	0.8118
UM vs. c+p	0.0037	0.0048	0.5223	0.0026	0.9975	<0.0001	0.0763	0.9107
UM vs. c	<0.0001	0.2338	0.8731	0.0018	0.0763	0.0006	0.0737	0.973

m - Maize, **l** - Leucaena, **g** - Gliricidia, **c** - Cowpea, **p** - Pesticides, **mu** - Mulch
UM - Unmanaged
mlgc - Alternating rows of Leucaena and Gliricidia
mlgc* - Alternating Leucaena and Gliricidia plants with the rows
SR - Short rains, **LR** - Long rains

Table 7: Percentage dominance (d) of some common species of beetles (Coleoptera) associated with the different cropping systems at Mtwapa

Species name	Ml	mg	Mlgc	mlg	mlgc*	mc	M	m+p	m-mu	ml+p	UM	c+p	c
Abacetus sp.(CA)	7.92	15.87	7.93	10.43	9.55	10.13	12.21	5.02	10.15	11.27	16.03	9.31	11.87
Brachypeplus sp. (N)	13.11	10.92	9.78	5.54	1.93	2.22	11.18	11.56	8.07	7.55	2.07	3.50	6.83
Carpophilus sp. (N)	0.19	6.28	3.26	1.84	1.36	-	1.54	9.38	3.79	8.00	1.37	0.12	1.71
Copris platus (S)	0.47	1.04	0.65	3.48	3.98	1.78	1.28	1.33	4.77	0.66	1.38	1.86	0.63
Drasterius aethiopicus (E)	2.83	2.54	2.39	1.96	2.61	2.31	3.21	4.27	3.67	1.42	2.07	4.82	6.38
Gonocephalum simplex (T)	33.96	19.46	32.83	27.61	37.95	48.80	35.98	26.91	33.13	32.39	27.76	30.67	27.61
Holosus sp. (ST)	2.45	4.64	1.85	3.04	3.55	4.53	1.28	0.57	1.83	1.42	5.86	5.15	2.16
Meristhus lepidotus (E)	15.84	15.72	21.84	9.13	11.59	13.33	15.55	21.80	15.04	14.67	4.66	21.91	15.29
Nudobius cephalus (ST)	0.19	4.94	0.98	1.52	0.68	0.89	0.64	0.28	0.61	1.53	1.56	3.18	1.80
Ornthophagus omostigma (ST)	1.41	1.49	0.65	0.33	3.41	0.18	1.67	0.38	0.61	3.17	10.34	0.99	1.26
Philonthus sp. (ST)	2.26	2.84	1.20	1.30	2.61	1.69	1.54	1.42	1.83	2.29	5.34	1.64	3.60
Systates amplicollis (CU)	5.28	3.59	2.61	3.47	1.70	1.33	2.70	3.70	2.32	4.49	1.55	1.20	1.71
Taraxides panctatus (T)	3.21	4.19	4.89	5.00	5.79	4.44	2.96	1.13	2.20	3.39	3.97	5.48	3.06
Tylotarsus sp. (E)	2.92	1.94	2.83	2.83	3.52	3.47	3.60	4.93	4.90	1.53	0.34	3.40	3.96

CA - Carabidae, **N** - Nitidulidae, **S** - Scarabidae, **E** - Elateridae, **ST** - Staphylinidae, **CU** - Curculionidae, **T**-Tenebrionidae

Table 8: Percentage dominance (d) of some common species of beetles (Coleoptera) associated with the different times of the LR (June - August 2000), SR (December 2000 - February 2001) and the inter-season period (September 2000) at Mtwapa

Species name	June	July	August	September	December	January	February
Abacetus sp.(CA)	31.52	11.71	5.27	6.63	5.31	3.49	0.68
Brachypeplus sp. (N)	3.36	2.37	9.06	16.31	7.24	3.28	2.28
Carpophilus sp. (N)	0.13	-	13.53	4.34	-	0.21	0.11
Copris platus (S)	4.36	2.14	1.17	1.30	1.25	0.56	-
Drasterius aethiopicus (E)	3.66	3.98	2.34	5.46	2.22	2.09	0.68
Gonocephalum simplex (T)	6.32	15.53	29.30	13.10	62.07	58.34	73.69
Holosus sp. (ST)	2.92	10.86	3.25	2.30	0.19	2.79	-
Meristhus lepidotus (E)	9.94	27.77	14.17	33.35	8.69	2.02	0.80
Nudobius cephalus (ST)	1.44	1.84	2.02	3.04	0.10	0.07	-
Ornthophagus omostigma (ST)	7.06	1.38	1.92	1.39	0.39	0.14	0.23
Philonthus sp. (ST)	2.44	3.98	3.04	4.12	0.68	0.42	0.91
Systates amplicollis (CU)	5.88	0.83	1.86	0.95	3.28	1.26	0.57
Taraxides panctatus (T)	0.57	0.15	3.36	0.26	1.64	16.68	12.64
Tylotarsus sp. (E)	3.97	5.36	2.08	2.99	2.61	1.19	4.44

LR - Long rains, **SR** - Short rains

CA - Carabidae, **N** - Nitidulidae, **S** - Scarabidae, **E** - Elateridae, **ST** - Staphylinidae, **CU** - Curculionidae, **T**-Tenebrionidae

Table 9: Species richness, Diversity and Evenness of ground dwelling arthropods during the SR and LR of 1999-2000 cropping seasons at Mtwapa

Treatments	S_Index	D_Index	H'_Index	J_Index
1. ml	7	2.736	0.461	0.736
2. mg	7.75	2.762	0.551	0.618
3. mlgc	8.25	2.23	0.431	0.48
4. mlg	7.25	1.685	0.346	0.411
5. mlgc*	7.25	1.685	0.378	0.442
6. mc	8.5	1.975	0.463	0.5
7. m	8	1.569	0.338	0.368
8. m+p	6.75	2.136	0.428	0.507
9. m-mu	6.75	1.795	0.307	0.403
10. ml+p	6	1.66	0.288	0.37
11. UM	8.25	2.531	0.551	0.594

m - Maize, **l** - Leucaena, **g** - Gliricidia, **c** - Cowpea, **p** - Pesticides, **mu** - Mulch, **UM** - Unmanaged, **mlgc** - Alternating rows of Leucaena and Gliricidia, **mlgc*** - Alternating Leucaena and Gliricidia plants with the rows, **SR** - Short rains, **LR**- Long rains

(b): Analysis of Variance

Diversity index	F (10,33)	Probability
Species richness (S)	0.96	0.491
Simpson - Yule diversity index (D)	0.97	0.489
Shannon Weiner diversity index (H')	0.76	0.662
Evenness (J)	8.09	<0.001

Table 10:Species richness (S), diversity (D and H') and evenness (J) of ground dwelling arthropods during the SR and LR of 2000-2001 cropping seasons at Mtwapa

Treatments	S_Index	D_Index	H'_Index	J_Index
1. ml	27.5 ± 0.65	7.671 ± 0.6	3.44 ± 0.09	0.25 ± 0.02
2. mg	25 ± 1.08	7.22 ± 0.47	3.34 ± 0.09	0.26 ± 0.01
3. mlgc	26.5 ± 1.55	7.89 ± 0.24	3.44 ± 0.04	0.24 ± 0.01
4. mlg	26 ± 2.86	8.06 ± 1.2	3.48 ± 0.19	0.28 ± 0.01
5. mlgc*	27 ± 1.28	7.99 ± 0.42	3.53 ± 0.04	0.29 ± 0.02
6. mc	25.25 ± 2.75	5.33 ± 0.52	2.89 ± 0.12	0.2 ± 0.01
7. m	24.25 ± 1.44	5.44 ± 0.5	2.94 ± 0.14	0.22 ± 0.01
8. m+p	24 ± 0.71	5.78 ± 0.71	2.98 ± 0.26	0.21 ± 0.01
9. m-mu	26.75 ± 1.11	4.81 ± 1.12	2.9 ± 0.03	0.22 ± 0.005
10. ml+p	25.75 ± 0.63	5.34 ± 0.62	2.86 ± 0.32	0.21 ± 0.01
11. UM	28.5 ± 0.65	9.76 ± 0.65	3.75 ± 0.02	0.32 ± 0.01
12. c+p	25.75 ± 1.89	5.42 ±1.89	3 ± 0.06	0.22 ± 0.01
13. c	28 ± 0.91	6.58 ± 0.91	3.29 ± 0.06	0.26 ± 0.03

m - Maize, **l** - Leucaena, **g** - Gliricidia, **c** - Cowpea, **p** - Pesticides, **mu** - Mulch, **UM** - Unmanaged, **mlgc** - Alternating rows of Leucaena and Gliricidia, **mlgc*** - Alternating Leucaena and Gliricidia plants with the rows, **SR** - Short rains, **LR**- Long rains

(b): Analysis of Variance

Diversity index	F (12,39)	Probability
Species richness (S)	0.79	0.661
Simpson - Yule diversity index (D)	5.46	0.0002
Shannon Weiner diversity index (H')	4.34	<0.0001
Evenness (J)	5.78	<0.0001

Table 11: Species richness (S), diversity (D and H') and evenness (J) of ground dwelling Beetles (Coleoptera) during the SR and LR of 2000-2001 cropping seasons at Mtwapa

Treatments	S_Index	D_Index	H'_Index	J_Index
1. ml	19.75 ± 0.85	5.4 ± 0.72	3.07 ± 0.12	0.34 ± 0.03
2. mg	17 ± 1.35	7.37 ± 0.53	3.28 ± 0.12	0.4 ± 0.02
3. mlgc	19.75 ± 1.31	5.46 ± 0.36	3.09 ± 0.11	0.53 ± 0.03
4. mlg	18 ± 2.12	7.2 ± 0.36	3.34 ± 0.03	0.41 ± 0.02
5. mlgc*	19.25 ± 1.12	8 ± 0.59	3.46 ± 0.06	0.43 ± 0.02
6. mc	17.75 ± 2.4	3.74 ± 0.51	2.62 ± 0.22	0.29 ± 0.03
7. m	16.5 ± 0.19	3.53 ± 0.34	2.53 ± 0.11	0.34 ± 0.06
8. m+p	17.25 ± 0.94	3.49 ± 0.48	2.48 ± 0.16	0.26 ± 0.02
9. m-mu	19 ± 0.71	3.53 ± 0.32	2.66 ± 0.09	0.34 ± 0.01
10. ml+p	17.5 ± 0.5	5.6 ± 0.36	3.04 ± 0.09	0.34 ± 0.01
11. UM	20.75 ± 0.75	8.6 ± 0.68	3.59 ± 0.08	0.47 ± 0.03
12. c+p	18 ± 1.78	4.83 ± 0.68	2.88 ± 0.14	0.33 ± 0.02
13. c	19.75 ± 0.48	4.77 ± 0.71	2.870.16±	0.34 ± 0.03

m - Maize, **l** - Leucaena, **g** - Gliricidia, **c** - Cowpea, **p** - Pesticides, **mu** - Mulch, **UM** - Unmanaged, **mlgc** - Alternating rows of Leucaena and Gliricidia, **mlgc*** - Alternating Leucaena and Gliricidia plants with the rows, **SR** - Short rains, **LR**- Long rains

(b): Analysis of Variance

Diversity index	F (12,39)	Probability
Species richness (S)	0.95	0.51
Simpson - Yule diversity index (D)	8.38	<0.0001
Shannon Weiner diversity index (H')	11.28	<0.0001
Evenness (J)	4.32	0.0002

Table 12: Probabilities of orthogonal contrasts on species richness (S), diversity (D and H') and evenness (J) of all ground dwelling arthropods and ground beetles (Coleoptera) trapped during the SR and LR of 2000-2001 cropping seasons at Mtwapa

	All ground dwelling arthropods				Ground dwelling beetles (Coleoptera)			
Treatment Contrasts	**S_Index**	**D_Index**	**H'_Index**	**J_Index**	**S_Index**	**D_Index**	**H'_Index**	**J_Index**
m vs. mc	0.6508	0.904	0.8023	0.3469	0.5127	0.7755	0.5992	0.2629
c vs. mc	0.4978	0.9834	0.7762	0.9082	0.4327	0.0898	0.0508	0.8165
mg vs. mlgc	0.4978	0.4639	0.7402	0.3768	0.1541	0.0149	0.2702	0.2684
ml vs. mlgc	0.6508	0.8129	1	0.9448	1	0.9385	0.9175	0.6567
mlg vs. mlgc	0.8208	0.8498	0.825	0.0708	0.3607	0.0254	0.1624	0.1258
mlg vs. mlgc*	0.6508	0.9408	0.8212	0.6449	0.5127	0.3047	0.4873	0.5976
ml vs. mg	0.261	0.6189	0.7402	0.4147	0.1541	0.0123	0.2288	0.1243
mlgc vs. mlgc*	0.4295	0.005	0.0034	<0.0001	0.4327	<0.0001	<0.0001	0.001
m vs. m+p	0.311	0.2065	0.1631	0.1197	0.3607	0.9411	0.9581	0.7866
c vs. c+p	0.9098	0.7066	0.8392	0.5726	0.694	0.9619	0.7919	0.0477
m vs. m-mu	0.261	0.4949	0.8373	0.9448	0.1941	0.9997	0.4604	0.8974
m vs. c	0.4978	0.9834	0.7762	0.9082	0.4327	0.0898	0.0508	0.8165
UM vs. ml	0.6508	0.0264	0.1274	0.0022	0.6001	0.0001	0.0049	0.0011
UM vs. Mg	0.1148	0.0077	0.066	0.0189	0.0546	0.1075	0.086	0.0595
UM vs. mlgc	0.3671	0.0451	0.1274	0.0018	0.6001	0.0002	0.0064	0.004
UM vs. mlg	0.9098	0.0059	0.0239	0.0062	1	0.0031	0.0134	0.0408
UM vs. mlgc*	0.4978	0.0597	0.275	0.3132	0.4327	0.4122	0.4553	0.3395
UM vs. mc	0.1462	<0.0001	0.0001	<0.0001	0.1209	<0.0001	<0.0001	<0.0001
UM vs. m	0.0498	<0.0001	0.0003	<0.0001	0.0304	<0.0001	<0.0001	0.0017
UM vs. m+p	0.0468	<0.0001	0.0005	<0.0001	0.0719	<0.0001	<0.0001	<0.0001
UM vs. m-mu	0.4295	<0.0001	0.0002	<0.0001	0.3607	<0.0001	<0.0001	0.0011
UM vs. ml+p	0.2171	<0.0001	<0.0001	<0.0001	0.0938	0.0003	0.0031	0.0017
UM vs. c+p	0.2171	<0.0001	0.0007	<0.0001	0.1541	<0.0001	0.0002	0.0008
UM vs. c	0.8208	0.0012	0.0293	0.0082	0.6001	<0.0001	0.0002	0.0018

m - Maize, **l** - Leucaena, **g** - Gliricidia, **c** - Cowpea, **p** - Pesticides, **mu** - Mulch
UM - Unmanaged
mlgc - Alternating rows of Leucaena and Gliricidia
mlgc* - Alternating Leucaena and Gliricidia plants with the rows
SR - Short rains, **LR** - Long rains

Figure 3a: Community dynamics of ground beetles (Carabidae, predators) in relation to selected herbivorous beetle families (Coleoptera)

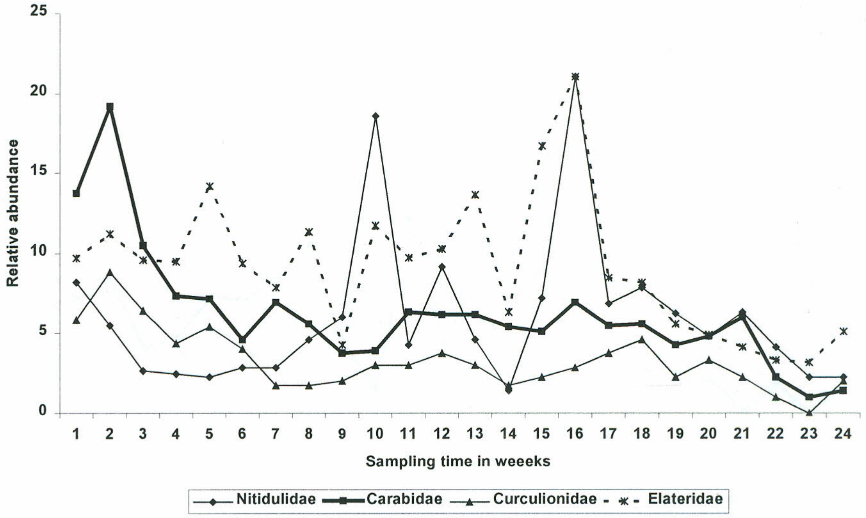


Figure 3b: Community dynamics of spiders (Aranae, predators) in relation to selected herbivoruous beetle families (Coleoptera)

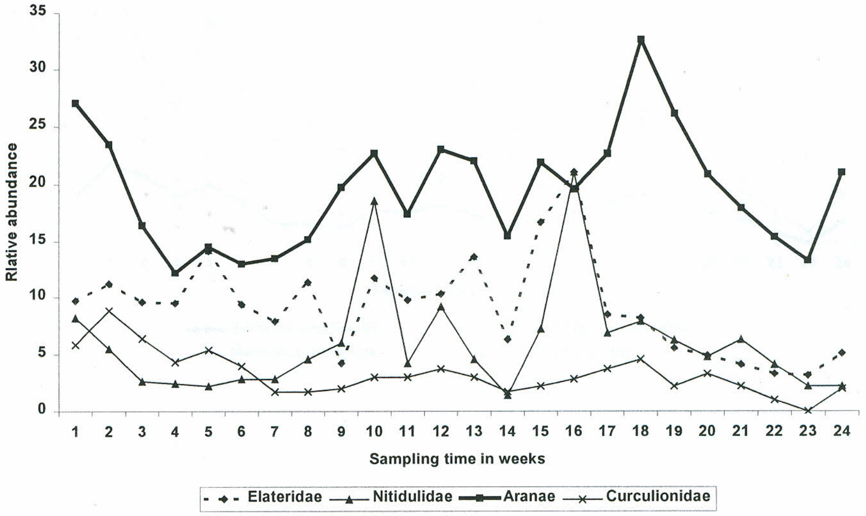


Figure 3c: Community dynamics of rove beetles (Staphylinidae, predators) in relation to selected herbivorous beetle families (Coloeoptera)

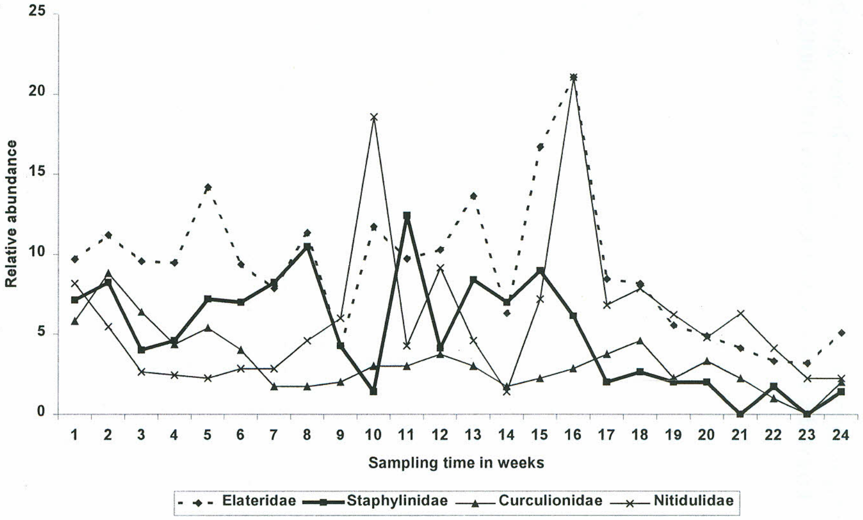


Figure 3d: Population dynamics of some dominant coleoptera species associated with the cropping systems at Mtwapa

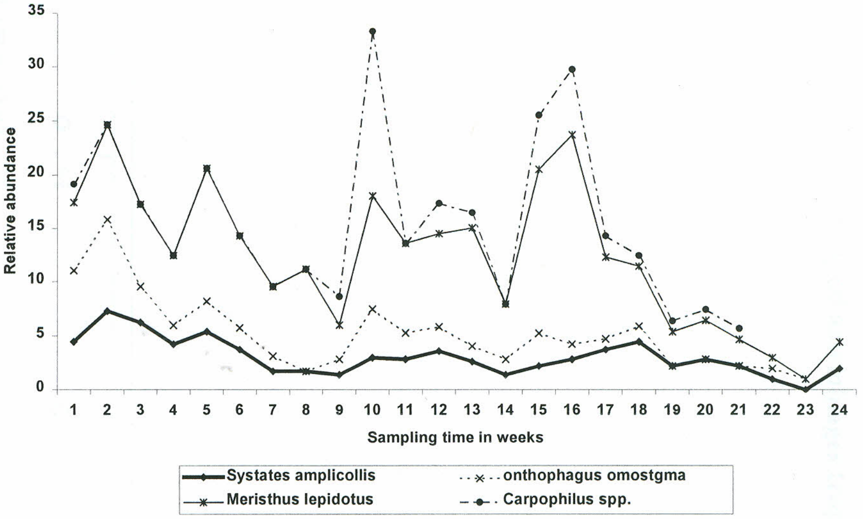
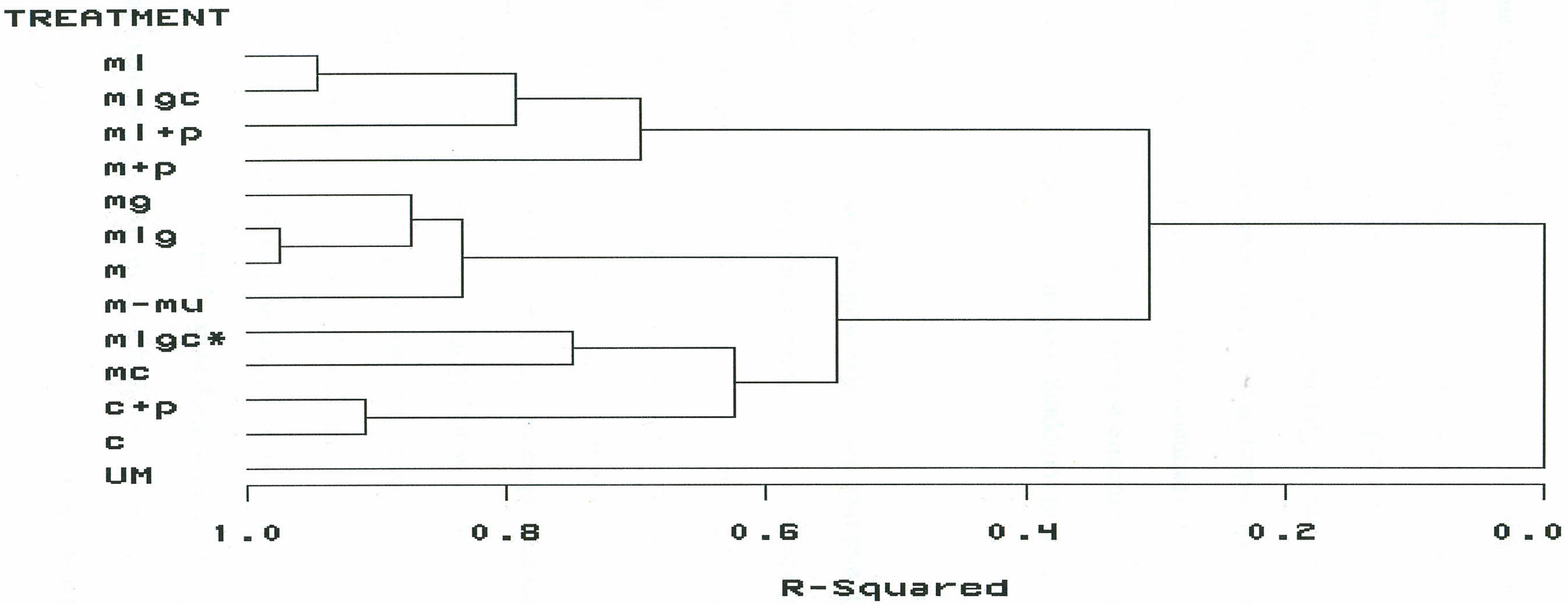


Figure 6:Dendrogram of similarity between cropping systems with respect to ground dwelling arthropod assemblages trapped during the SR and LR of 2000-2001 cropping seasons at Mtwapa



m - Maize, **l** - Leucaena, **g** - Gliricidia, **c** - Cowpea, **p** - Pesticides, **mu** - Mulch
UM - Unmanaged
mlgc - Alternating rows of Leucaena and Gliricidia
mlgc* - Alternating Leucaena and Gliricidia plants with the rows
SR - Short rains, **LR** - Long rains

3.2 DISCUSSION

3.2.1 Effect of cropping systems on relative abundance and dynamics of ground dwelling arthropods

The dominance of ants (Formicidae) in pitfall trap samples have been observed in other surveys mainly in the coastal tropical forests (e.g., Adis, 1988; Stork, 1988). This reflects the status of the ants as one of the most numerous tropical arthropods (Wallwork, 1976), which are well adopted to dry surface conditions (Janzen and Schoener, 1968), and which generally forage widely in coastal forest floor (Burgess *et. al.,* 1999) as well as in agricultural systems as observed in this study. Termites were scarce in all the samples although they have been reported to be abundant in other studies at the coast (Goald *et. al.,* 1994). The scarcity in this study is possibly because they have very aggregated distributions (Stork, 1993), and that they rarely walk uncovered on the soil surface (Burgess *et. al.,* 1999).

The effect of cropping systems on the species composition and arthropod community structure is clearly seen in the preference for some arthropod families to particular treatments while being almost absent in others. For example blister beetles (Meloidae) were more abundant in cowpea monocrops. The most dominant species *Epicautta albovittata* (stripped blister beetle), a well known pest of legumes and pulses (Hill, 198), was more dominant in cowpea plots than in plots without cowpea. The Coccinellidae beetles, which have been reported as natural enemies of aphids (Jervis and Kidd. (1997), and used successfully as biological control for the same, (Dixon, 1998), were also more dominant in cowpea monocrops than in the other treatments. A number of herbivorous species known to attack cereals were seen to be more abundant in plots that contained maize than in those without maize (Hill, 1983). These include *Carpophilus spp.* (corn sap beetles: Nitidulidae), *Diobrotica spp.* (Chrysomellidae), *Nematocerus spp.* (Shiny cereal beetles: Curculionidae), and *Systates amplicollis* (Systates weevils: Curculionidae) among others.

These results indicate that agricultural systems may serve as insect reservoirs and that absence of a specific host plant implies absence of the pest species. Decreased pest abundance after harvesting further illustrates this phenomenon. However there were a number of arthropod families that seemed not to be selective in their distribution in response to cropping systems in this study and were present in all the treatments although in different population densities. They include the spiders (Aranae), Crickets (Gryllidae), Cockroaches (Blattoidea) and Ants (Formicidae) among others, most of which are generalists predators or polyphagous (Hill, 1983).

There was a notable difference in response to rainfall patterns by different arthropod families. Some families (Carabidae, Elateridae, Nitidulidae, and Formicidae) had highest population densities in the month of August 2000 when there was high rainfall while the abundance of Tenebrionidae and Curculionidae decreased following increased rainfall amounts during the 2000-2001 cropping seasons. During low rainfall, plants are likely to undergo stress making them susceptible to pests attack and this explains why pest populations are high during low rainfall (Hill, 1983). The abundance of spiders (Aranae) seemed to increase shortly after the onset of rains and the increased populations of herbivorous species. There is evidence that arthropod densities are regulated by a number of physical factors like rainfall and temperatures, which have been shown to influence soil characteristics such as moisture (Hengeveld 1979) and pH (Gruttke and Weigmann 1990).

3.2.2 Effect of cropping systems on species richness and diversity of ground dwelling arthropods

3.2.2.1 Effect of managed systems in comparison to unmanaged systems

Management of agricultural systems can actually lower species diversity and richness as indicated by the significant high species richness and diversity in the unmanaged system compared to the managed systems in this study. There is therefore need to maintain an adjacent natural system close to the managed systems. Natural areas adjacent to the managed agricultural systems can provide habitat for pollinators and natural enemies of pests (Power and Flecker, 1996). However this research has shown that increasing crop diversity within agricultural systems can increase species richness and diversity to levels close or equal to that of the unmanaged systems. This is evident by the lack of significant difference in diversity, species richness and evenness between unmanaged systems and some treatments with high plant diversity and those with agroforestry tree species. There was also no significant difference in the number of some predatory species between the unmanaged and the agroforestry plots. This implies that within the agroecosystems, increasing crop diversity through the use of polycultures can augment the resources available to pollinators and pests' natural enemies, resulting in higher populations of beneficial organisms (Andow 1991) and therefore high species richness and diversity.

Other studies comparing natural systems with traditional and with commercial cropping systems have shown that traditional systems are significantly more diverse than conventional, commercial systems and that they seldom approach the diversity of surrounding natural systems (Power and Flecker, 1996). These traditional systems include multiple cropping systems like intercropping and alley cropping, which do not require the use of agrochemicals, as opposed to monocultures, in which inorganic rather than organic inputs are preferred.

3.2.2.2. Effect of intercropping on species richness and diversity of ground dwelling arthropods

The low diversity of ground dwelling arthropods in maize monocrop indicates that multiple cropping systems are likely to support more arthropod species than the monocultures. Modern commercial agriculture is dominated by monoculture, and this reduced plant diversity influences the composition and abundance of the associated biota, such as, pollinators, insect pests, their natural enemies, and microorganisms (Matson *et. al.,* 1997).

The high species diversity and richness, as well as high arthropod abundance in the cowpea monocrop was however expected. The reason for this is that many species may prefer the microhabitat provided by the cowpea crop, which provides a good ground cover. This vegetation cover in turn influences the microclimate (such as moisture, pH and temperature) at ground level (Gardner, 1991) which have been shown to affect the abundance and diversity of soil arthropods ((Baker and Dunning, 1975; Thiele, 1977; Hengeveld, 1979, Gruttke and Weigmann, 1990; Holopainen *et. al.,* 1995). In addition, it creates a suitable microhabitat for many arthropod species, which use it as refugia. Cowpea has also been associated with a complex of insect pests, which are the greatest constraint to good cowpea yield in many tropical and sub-tropical countries (Singh and Jackai, 1985).

3.2.2.3 Effect of agroforestry as a multiple cropping system on species richness and diversity of ground dwelling arthropods

Since alley cropping is an agroforestry system that integrates traditional agricultural practices with aspects of forest management it is not surprising that some managed treatments (those with agroforestry tree species) had greater diversity than the unmanaged plots as observed in the 1999-2000 data. The combination of trees and crops should provide greater arthropod niche diversity in both time and space than the monocultures as well as the polycultures of annual crops (Stamps and Linit, 1998). Increased niche diversity in turn leads to increased insect species richness including both insect herbivores and their natural enemies, thus decreasing the probability that a single herbivore dominates the community.

3.2.2.4 Implications to conservation of arthropods

The deliberate association of trees with agronomic crops can result in insect management benefits due to the structural complexity and permanence of trees and to their modification of microclimates and plant apparency within the production area (Stamps and Linit, 1998). Including agroforestry trees within agroecosystems means incorporating the complex system of the tree component. Since trees are larger and more complex in their architecture and live longer than annual crops and herbaceous plants, then arthropod diversity is greater in trees than in annual and herbaceous plants (Lawton, 1978).

Several studies have indicated that trees support a significantly more diverse arthropod community than shrubs or herbaceous annuals and perennials (Lawton and Schroder, 1977; Strong and Levin, 1979; Niemala *et. al.,* 1982), which have been attributed to the structural complexity of trees compared to other types of plants. Trees can provide natural enemies with alternate sources of pollen and nectar, alternate hosts, and stable refuges (Stamps and Linit, 1998). Trees also satisfy a great number of non-nutritional arthropod needs such as sites for mating, oviposition, hiding, resting, aestivation and wintering. The absolute physical area and biomass available for the arthropods are greater in trees than in other plants, as well. In addition the phenology and longevity of the trees enhances temporal niche diversity (Stamps and Linit, 1998).

Since trees are perennial, the heterogeneity of temporal patterns of plant development in an agroforestry system could make a major contribution to insect diversity (Stamps and Linit, 1998) and thus insect conservation.

3.2.3 Effect of cropping systems to predatory ground dwelling arthropods

3.2.3.1 Effect of intercropping

There was a clear evidence of the predominance of predatory species in the intercropped plots compared to monocropped plots. Similar studies on soil dwelling predator density and diversity in agroecosystems have indicated significantly greater densities and diversity as well us greater predator activities (predation) in multiplantings than in monocultures (Altieri and Whitecomb, 1979; Blomberg and Crossly, 1983; Stinner et al., 1984). Because a less diverse resource base is available, low genetic and species diversity of the crop results in less abundance and diversity at higher trophic levels, such as predators (Matson *et. al.,* 1997). This explains why spider and ground beetle abundance was less in the maize monocrop as opposed to the greater spider and ground beetle abundance in all the plots that had agroforestry tree species and thus increased plant diversity. Murdoch *et. al.* (1972) found insect diversity highly correlated to plant structural diversity.

3.2.3.2 Effect of agroforestry

There was equally a clear evidence of the predominance of predatory species in the plots with agroforestry tree species as compared to all the other plots. There was however no significant difference in the relative abundance of some predatory species between the unmanaged and the agroforestry plots. This implies that within the agroecosystems, increasing crop diversity through the use of polycultures can augment the resources available to pollinators and pests natural enemies, resulting in higher populations of beneficial organisms (Andow 1991) and therefore high species richness and diversity.

Individual plants in annual cropping systems are usually highly synchronized in their phenology and short-lived. This lack of temporal continuity is a problem for natural enemies because prey availability is limited to short periods of time and refugia and other resources are not available consistently.

3.2.3.3 Implications to agriculture

The "natural enemies hypothesis" which posits that vegetational diversity increases both population size and impacts of natural enemies that regulate population size of herbivorous arthropod pests (Root 1973, Risch 1983, Herzog and Funderburk 1986, Russel 1989, Andow 1991), has been proposed to explain the above observations. Increasing vegetational diversity in agroecosystems, increases system stability and decreases the incidence of major insect pest outbreaks observed in some monocultures (Perrin 1977, 1980; Altieri and

Letourneau 1982; Risch, 1983; Risch *et. al.,* 1983; Andow 1991). The "enemies hypothesis" (Root, 1973), has been proposed to explain this significant increase in predator densities in multicultural as compared to monocultural systems. Based on this observation, successful pest control has been achieved through crop diversification. A very good example is triculture of maize (*Zea mays*), faba bean (*Vicia faba*) and squash (*Curcubita moschata*) in Central Mexico. Tricultures exhibited less damage from pests than the maize monocultures because of increased predation of aphids and lower mite colonization (Trujillo-Arriaga and Altieri, 1990). This increase in abundance and diversity of arthropod predators and parasitoids are attributed largely to the increased availability of suitable microhabitats, and diverse food resources such as nectar, pollen, and alternate hosts or prey (Root 1973, Vandermeer 1990). Such nutrient sources frequently result in increased longevity and fecundity of natural enemies, and these benefits may strengthen both their functional and numerical responses (Price *et. al.,* 1980).

Similarly, higher abundance and greater impact of some predatory communities (natural enemies) have been reported in vegetationally complex than in simple agroecosystems (Brust *et. al.,* 1986, Perfecto *et. al.,* 1986), and as observed in this study. This study therefore does support "natural enemies hypothesis" and contradicts other similar studies that have reported no evidence of this hypothesis. For instance, Risch *et. al.,* 1983, and Andow and Risch 1985 reported that predation rates on egg masses of the European corn borer *Ostrinia nubilalis*

(Hubner) by a predaceous beetle, *Coleomegilla maculata* (DeGeer), were significantly higher in maize monocultures than in the more densely planted maize/ bean/ squash polyculture. Moreover, another review of the natural enemies hypothesis reported that 9.3% of the predator species studied had lower densities in polycultures, whereas 13.2% did not show any difference (Andow 1991). Ogol, *et. al.* (1998) found no evidence of the natural enemies hypothesis regarding parasitism in the maize - leucaena agroforestry system. In their study, greater proportion of eggs were preyed upon in the maize monocrop than in the intercrops, indicating that alley cropping leucaena with maize did not increase, and in certain cases, reduced the abundance or activity of the natural enemies of stem borers, therefore contradicting the natural enemies hypothesis.

3.2.4 Effect of cropping systems to herbivorous ground dwelling arthropods

3.2.4.1 Effect of intercropping

Herbivorous arthropods were predominantly more in the monocropped plots than the unmanaged, intercropped and the alley cropped plots. Diversification of cropping systems has therefore been suggested as a means to ameliorate insect pest problems associated with monocultures (Baliddawa, 1985).

The deployment of multi-species cropping systems to increase plant diversity and thereby decrease pest problems has been investigated and the results, though mixed, are generally positive (Rish *et. al.,* 1983; Baliddawa, 1985; Andow, 1991). In his comprehensive review of 209 studies on 287 species of insect herbivores, Andow (1991) reported approximately 52% of the species had lower densities in polycultural compared to monocultural cropping systems. Only 15% had higher densities. Ogol *et al.* (1999) reported that colonization by maize - stem borers was significantly reduced in the maize - leucaena intercrops in comparison with the maize monocrop. Their results were consistent with reports for other plant - herbivore systems in which there were fewer colonizing adults in polycultures than in monocultures (Bach, 1980a, b; Rish 1980; Coll and Bottrell, 1994), and with those in which intercropped maize received fewer egg masses than moncropped maize (IRRI, 1974; Suryatna, 1976; Coll and Bottrell, 1994).

3.2.4.2 Effect of agroforestry

There was high abundance of herbivorous species in the plots with low plant diversity (monocropped plots) as compared to the alley cropped plots. It is possible that shade from trees may have reduced pest densities in intercrops. In fact tall intercrops and thick groundcover have been shown to cause a dramatic influence on almost all microclimate variables (heat input, wind speed, soil dessication and temperature) (Forman and Baundry, 1984; Epila, 1991; Heisler and Dix, 1991; Stinner and Tonhasca, 1991). They also alter the reflectivity, temperature and evapotranspiration of shaded plants or at the soil surface, which in turn could affect insects adapted to specific microclimatological ranges (Cromartie, 1981; Stinner and Tonhasca, 1991). Risch, (1981) found that shade dramatically reduced the number of three Chrysomelid pests on beans and squash in shade screen experiment and found that the date correlated well with reduced beetle numbers in fields shaded corn stalks. The effectiveness of shade in reducing herbivores has also been shown in non-agricultural systems (Huffaker, 1959; Hicks and Tahvanainen, 1974).

3.2.4.3 Implications to agriculture

Crops grown in conventional monoculture systems have been shown to suffer from severe pest problems, since monocultures reduces a complex natural plant system to a single-species community. This can lead to decreased insect diversity and can promote rapid population growth of a single or very few insect pest species (Cromartie, 1981; Altieri, 1992).

The "resource concentration hypothesis" (Root, 1973), which suggests that non-host plant species disrupt the ability of pest to attack its proper host efficiently (Vandermeer, 1990), has been proposed to explain this phenomenon of greater herbivore numbers in simple than diverse habitats. Results in this study therefore, accords with the resource concentration hypothesis.

Although far from being universal, it appears that populations of insects herbivores are frequently lower in polycultures than in monocultures of the same crops (Risch *et. al.,* 1983), and as observed in this study. Agroforestry as a multiple cropping system therefore, has the potential to reduce pest problems by one way of increasing the abundance and diversity of insect predators and thus reducing agricultural input in the form of the large amounts of pesticides required for the control of pests in monocultures. It is worth noting however that enhancing greater predator abundance and diversity may not be the only way that agroforestry systems help to reduce pest problems.

3.2.5 Effect of pesticides on relative abundance, species richness and diversity of ground dwelling arthropods

The use of pesticides was shown to adversely interfere with species richness, diversity and abundance of some selected arthropod families. The low species richness and diversity in treatments in which pesticides were used is a clear indication of the nature of pesticides in killing and injuring a variety of non target organisms (Theiling and Croft 1988), thus lowering arthropod diversity in agroecosystems. The insect pest populations in this study, for instance click beetles (Wireworms - Elateridae) and weevils (Curculionidae), were observed to decrease to zero as long as pesticides were being used (during the cropping period), followed by population explosions after harvesting. This observation indicates the increased demand for pesticide use in monocultures for every subsequent season following population explosions after pesticide use in the previous season. Since genetically uniform monocultures are more vulnerable to pests and diseases, a condition clearly illustrated by the high abundance of weevils in the maize monocrops than the intercrops in this study, they therefore require higher inputs of pesticides.

Elsewhere, the phenomenon of pest resurgence brought about by the application of pesticides and the inadvertent elimination of pest's natural enemies reveals dramatically the significant impact the latter normally have (Debach and Rosen; 1991, Shepard and Ooi, 1991). Minimising the use of agrochemicals such as pesticides can therefore be achieved through intercropping and alley cropping, which helps to increase plant diversity in agroecosystems thus reducing the pest pressure by doing away with single herbivore (pest) populations common in monocultures. This results in the conservation of beneficial organisms and the conservation of important functional processes such as predation, decomposition and nutrient cycling (Matson *et. al.,* 1997).

CHAPTER FOUR

GENERAL DISCUSSIONS, CONCLUTIONS AND RECOMMENDATIONS

This research is with no doubt a major contribution to arthropod diversity research in tropical agroforestry systems. There is a an immense amount of data on the effect of agroecosystems management practices on the diversity of arthropods especially in the temperate systems, as well as the effect of management of natural systems like forests and parks. However there is no work that has been reported on the effect of agroforestry systems on the same both in the tropical and temperate ecosystems.

Stamps and Linit (1998) reviewed various research findings in multiple cropping systems as well as forestry and silviculture, and used the available information to predict what would be the effect of agroforestry to arthropod communities. It was clear in their review that the effects of agroforestry systems, such as alley cropping, on the diversity of arthropod communities and the subsequent levels of insect herbivore damage are largely unknown. However they pointed out that experimental evidence from agroecosystems and forestry systems suggests that herbivore damage is lower in complex plant systems than in single species systems. This was seen to be encouraging for agroforesters since it was predicted that agroforestry systems may provide opportunities to noticeably increase arthropod diversity and lower pest populations compared to the polycultures of annual crops or trees by themselves. One of their recommendations was the need for general studies on the differences in arthropod populations between agroforestry and traditional agronomic systems. The present research has greatly contributed to this recommendation by providing baseline data on the effect of alley cropping on arthropod communities compared to other agronomic systems and the natural systems.

One of the greatest challenges in agriculture has been to do away with the modern agricultural practices that have proved to be unrealistically expensive to the majority of farmers especially in the Sub-Saharan region. Modern agriculture is not only harmful to human health due to increased use of chemicals, but also a major threat to biodiversity and thus ecosystem structure, functioning and sustainability. This study have further contributed to the knowledge on the effect of pesticides use as well as agronomic practices of monocultures in lowering arthropod diversity and allowing pest populations explosions. In addition, it has come out very clearly that agroforestry systems involving alley cropping are likely to be more diverse than even the undisturbed seminatural systems. This makes agroforestry an important tool in developing the most needed integrated pest management technologies. By maintaining a more diverse and complex arthropod community, agroforestry helps to sustain a more or less natural ecosystem structure with functional processes that help to maintain pest populations at manageable levels by maintaining high diversity of predator species. This leads to less need for agricultural inputs as well as achieving economical land use patterns much needed in the Sub-Saharan Africa.

In Order to effectively tap the potentials that agroforestry offer to modern agriculture and food production, there is increased demand for the integration of knowledge in agronomy and forestry, since in agroforestry the two (trees and crops) are expected to positively interact to produce the required results. These two disciplines may have very different perceptions of agroforestry's impact on arthropod diversity. Coming from a traditional agroecosystems background, agronomists may see agroforestry as having dramatic effects in increasing arthropod diversity (as revealed in this study) and improving pest control. On the other hand, the foresters, having traditionally dealt with maintaining natural stands of trees, may see agroforestry as decreasing biodiversity. In either case, agroforestry may provide an attractive combination of economic and ecological benefits, not the least of which is the possibility of fewer insect pests problems resulting from increased arthropod diversity compared to traditional agricultural practices.

This study demonstrate the importance and the potential of agroforestry practices in enhancing insect conservation efforts as well as influencing future management practices in agroecosystems. The data presented here also demonstrates that diversification of agricultural systems through alley copping increases species richness and arthropod diversity, which is closely comparable to that of the unmanaged systems. This study therefore suggests that tropical agroecosystems are important for the conservation of biological diversity than previously thought. It also calls attention to the potential for significant biological diversity increase with increasing vegetation diversity as compared to the low input monocultured systems. As this study has revealed that some diverse agroecosystems have the capacity to maintain a high diversity of arthropods, more careful attention should be focused on designing of agroecosystems in general, but particularly adjacent to highly diverse natural systems. Agroecosystems that maintain similar microclimate to that of the natural areas, as well as contain high planned biodiversity, (i.e. the diversity of the plants that the farmer chooses to include in the system) can provide abundance diversity of food, nesting, living, and hiding places for arthropods. Such systems can as well be used for conservation purposes the same way natural habitats have been utilized for the same purpose.

In summary this study as well as others (Paoletti and Pimentel, 1992; Hawksworth, 1993 and Perfecto *et. al.,* 1997), suggests that agroecosystems could be compatible with conservation objectives. Moreover careful planning of the mosaic agroecosystems and agroforestry systems that surround natural preserves is not only recommended but perhaps also necessary for future conservation of biodiversity in the tropics.

I therefore propose the following as some of the most important 'eye opening' areas of research in agroforestry that will go a long way in understanding and incorporating different agroforestry systems based on specific needs into our modern agriculture: -

1. The effect of agroforestry should be narrowed to specific predator species diversity especially the carbide beetles and the spiders. This study was not able to limit itself to species level of spiders due to taxonomic limitations. The number of carabid species that I was able to identify was few thus not allowing comparison of species richness and diversity within the carabid community.
2. The prey predator relationships in agroforestry between specific pest species and their natural enemies should be evaluated in comparison with traditional agroecosystems and natural systems.
3. Research into the specific mechanisms behind enhancement of pest management with agroforestry practices, and the basic research into the life histories of pests and potential natural enemies is also vital in increasing the knowledge about agroforestry systems processes and functioning.
4. There is need to establish whether there are other mechanisms through which agroforestry practices helps to ameliorate pest problems, apart from enhancing greater insect predator abundance and diversity, and such mechanisms need to be investigated.

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